NITRATE AND PHOSPHORUS REMOVAL FROM MUNICIPAL WASTEWATER TREATMENT PLANT EFFLUENT USING PHYTOREMEDIATION

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CERTIFICATION OF APPROVAL

Nitrate and Phosphorus Removal from Municipal Wastewater Sewage Treatment Plant Effluent Using Phytoremediation

by

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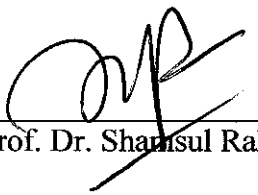

(Assoc. Prof. Dr. Shamsul Rahman Mohamed Kutty)

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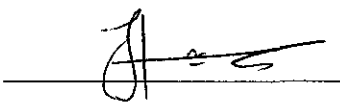
TRONOH, PERAK

July 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



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ABSTRACT

Water hyacinth has been used in aquatic systems for wastewater purification in many years worldwide. The role of water hyacinth (*Eichhornia crassipes*) species in polishing nitrate and phosphorus concentration from municipal wastewater treatment plant effluent by phytoremediation method was evaluated. The objective of this project is to determine the removal efficiency by water hyacinth in polishing nitrate and phosphorus, as well as chemical oxygen demand (COD) and ammonia. Water hyacinth is considered as the most efficient aquatic plant used in removing vast range of pollutants such as organic matters, nutrients and heavy metals. Water hyacinth, also referred as macrophytes, were cultivated in the treatment house in reactor tank of approximately 90(L) x 40(W) x 25(H) in dimension and built with three compartments. Three water hyacinths were placed in each compartments and water sample in each compartment were collected in every two days. The plant observation was conducted by weight measurement, plant uptake and new young shoot development. Water hyacinth effectively removed 49% of COD, 81% of ammonia, 67% of phosphorus and 92% of nitrate. It also showed significant growth rate at starting from day 6 with 0.33 shoot/day and they kept developing up to 0.38 shoot/day at the end of day 24. Thus, from the studies conducted, it was proved that water hyacinth is capable of polishing the effluent of municipal wastewater which contains undesirable amount of nitrate and phosphorus concentration.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background studies

In recent years many of the waterways and lakes in the world have become enriched with nutrients, mainly nitrogen and phosphorus resulting in eutrophication. This has occurred due to the entry of nutrients from several diffuse and point sources of pollution. Most domestic area lack the appropriate wastewater treatment plants specifically mean to remove nutrients. Hence, phytoremediation seems to be the emerging environmental friendly technology that can be used to clean up nutrients as a tertiary treatment process (Jayaweera and Kasturiarachchi, 2004).

The municipal wastewater contains important constituents of concern in wastewater treatment. Those constituents are: suspended solids, biodegradable organics, pathogens, nutrients, priority pollutants, refractory organics, heavy metals, and dissolved organics. For this project, nutrients mainly nitrate and phosphorus is the main concern in the municipal wastewater treatment using phytoremediation method. Nutrients, which include nitrogen, carbon and phosphorus, are essential for the growth of undesirable aquatic plants, microorganism, and animals. When nutrients are discharged in excessive amounts on land, they can lead to the pollution of groundwater. Phosphorus, on the other hand is responsible for the growth of algae and other biological organism. Because of noxious algal blooms that occur in surface water, the amount of phosphorus that enters surface water should be controlled (Metcalf and Eddy, 2004).

Phytoremediation method is an emerging treatment method that is low cost and low technology compared to the existing conventional treatment method. Basically, it is the use of green plant, including aquatic macrophytes, grasses, forbs, woody species and reeds, to remove contaminants in wastewater (Hinchman et.al, 1997).

1.2 Problem statement

Municipal wastewater is treated by the sewage treatment plant (STP) which consists of several treatment processes. But since there is no nitrification process occurs in the aeration tank, the treated effluent released from sewage treatment plant contains undesirable nitrate and phosphorus concentration. The undesirable amount of nitrate and phosphorus could lead to eutrophication problems. Therefore, a post-treatment of effluent wastewater is introduced in polishing the nitrate and phosphorus concentration using water hyacinth. Phytoremediation technology of removing contaminants from wastewater was discovered to be the new technology for wastewater treatment. Basically, this method describes the treatment of environmental problems through the use of certain plants. It is the least harmful method because it uses naturally occurring organisms and preserves the natural state of the environment. Moreover, the plants can be easily monitored which can reduce the maintenance cost indirectly.

1.3 Objective

This project focuses on the effectiveness of water hyacinth in removing nitrate and phosphorus from UTP's sewage treatment plant (STP) effluent. It is also conducted to provide data of municipal wastewater treatment for post treatment purposes.

1.4 Scope of study

The scope for the first semester are designing the reactor tank and acclimatizing the Water Hyacinth. While the second semester focuses in determining the removal efficiency of Nitrate and Phosphorus from effluent municipal wastewater.

The scopes of this study are:

1. The rate of nitrate, phosphorus, ammonia and COD removal from the municipal wastewater treatment plant effluent.
2. Growth observation and plant uptake of water hyacinth.

CHAPTER 2

LITERATURE REVIEW

2.1 Municipal wastewater constituent

Wastewater is characterized in terms of its physical, chemical and biological treatment. Physical characteristics include taste, odour, temperature, color and turbidity. Meanwhile, chemical characteristics define pH, hardness, alkalinity, Iron and manganese, toxicity, and dissolved solids. The most important constituent of concern wastewater treatment are nutrients, suspended solids, biodegradable organics, pathogens, priority pollutants, refractory organics, and dissolved in organics (Metcalf and Eddy, 2004).

2.1.1 Nitrate

For this study, nitrate and phosphorus removal are the main concern in treating the effluent municipal wastewater. The element nitrate and phosphorus, essential to the growth of microorganism, plants, and animal, are known as nutrients or biostimulatants. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater (Metcalf and Eddy, 2004).

In inorganic chemistry, a nitrate is a salt of nitric acid with an ion composed of one nitrogen and three oxygen atoms (NO_3^-). In organic chemistry the esters of nitric acid and various alcohols are called nitrates. High levels of nitrates, most often through occupational exposure in adults, are toxic to humans. Nitrates oxidize the iron atoms in hemoglobin from Ferrous Iron (2+) to Ferric Iron (3+), rendering it unable to carry oxygen. This condition is called methemoglobinemia and can lead to a lack of oxygen

in tissues. Infants, in particular, are especially sensitive to methemoglobinemia as a result of nitrate exposure. This is most often caused by high levels of nitrates in drinking water (Black and Babers, 1939).

In freshwater or estuarine systems close to land, nitrate can reach high levels that can potentially cause the death of fish. While nitrate is much less toxic than ammonia or nitrite, levels over 30 ppm of nitrate can inhibit growth, impair the immune system and cause stress in some aquatic species. In most cases of excess nitrate concentrations in aquatic systems, the primary source is surface runoff from agricultural or landscaped areas which have received excess nitrate fertilizer. Consequently, as nitrates form a component of total dissolved solids, they are widely used as an indicator of water quality (Black and Babers, 1939).

2.1.2 Phosphorus

Phosphorus is the chemical element that has the symbol P and atomic number 15. Phosphorus compounds are also widely used in explosives, nerve agents, friction matches, fireworks, pesticides, toothpaste and detergents. Phosphorus being an essential plant nutrient, finds its major use as a constituent of fertilizers for agriculture and farm production in the form of concentrated phosphoric acids, which can consist of 70% to 75% P_2O_5. Global demand for fertilizers led to large increase in phosphate (PO_4^{3-}) production in the second half of the 20th century. Due to the essential nature of phosphorus to living organisms, the low solubility of natural phosphorus-containing compounds, and the slow natural cycle of phosphorous, the agricultural industry is heavily reliant on fertilizers which contain phosphate, mostly in the form of superphosphate of lime (Anderson, 1996)

Phosphorus, on the other hand is also essential to growth of algae and other biological organism. Because of noxious algal blooms that occur in surface water, there is presently much interest in controlling the amount of phosphorus compounds that enters surface waters in domestic and industrial waste discharges and natural runoff.

Phosphorus is an essential macromineral for plants, which is studied extensively in edaphology in order to understand plant uptake from soil systems. In ecological terms, phosphorus is often a limiting factor in many environments (Metcalf and Eddy, 2004).

2.2 Eutrophication

Eutrophication is an increase in chemical nutrients, typically compounds containing nitrogen or phosphorus in an ecosystem. It may occur on land or in water. Although eutrophication is commonly caused by human activities, eutrophication can also be a natural process in lakes. Thus, eutrophication is a natural condition for many lakes. Eutrophication is however often used to mean the resultant increase in the ecosystem's primary productivity such as excessive plant growth and decay, and further effects including lack of oxygen and severe reductions in water quality, weiners, and other animal populations. This situation is further showed as in Figure 1 (Wikipedia, August 2008).

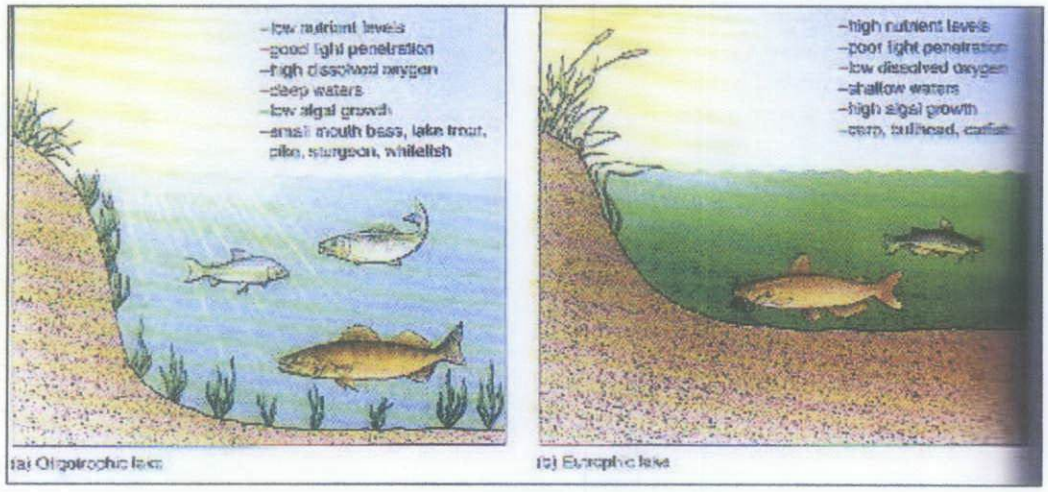


Figure 1: Eutrophication

Phosphorus is often regarded as the main culprit in cases of eutrophication in lakes subjected to point source pollution from sewage. The concentration of algae and the trophic state of lakes correspond well to phosphorus levels in water. Some algal blooms

are toxic to plants and animals. The toxic compounds which they produce can make their way up the food chain, resulting in animal mortality. Freshwater algal blooms can pose a threat to livestock. When the algae die or are eaten, neuro- and hepatotoxins are released which can kill animals and may pose a threat to humans (Wikipedia, August 2008).

Human activities can accelerate the rate at which nutrients enter ecosystems. Runoff from agriculture and development, pollution from septic systems and sewers, and other human-related activities increase the flux of both inorganic nutrients and organic substances into terrestrial and aquatic ecosystems. Elevated atmospheric compounds of nitrogen can increase nitrogen availability. Phosphorus is often regarded as the main culprit in cases of eutrophication in lakes subjected to point source pollution from sewage. The concentration of algae and the trophic state of lakes correspond well to phosphorus levels in water as shown in Figure 2. Studies conducted in the Experimental Lakes Area in Ontario have shown a relationship between the addition of phosphorus and the rate of eutrophication. Humankind has increased the rate of phosphorus cycling on Earth by four times, mainly due to agricultural fertilizer production and application (Wikipedia, August 2008).

Figure 2: Eutrophication causes algal blooms in lake

2.3 Green algae

The green algae, as shown in Figure 3, are the large group of algae from which the embryophytes (higher plant) emerged. As such, they form a paraphyletic group, although the group including both green algae and embryophytes is monophyletic. The green algae include unicellular and colonial flagellates, usually but not always with two flagella per cell, as well as various colonial, coccoid and filametous forms. In the Charales, the closest relatives of higher plants, full differentiation of tissues occurs. There are about 6000 species of green algae. Many species live most of their life as single cell, while other species form colonies or long filaments (Wikipedia, November 2008).

A few other organisms rely on green algae to conduct photosynthesis for them. The chloroplasts in euglenids and chlorarachniophytes were acquired from ingested green algae, and in the latter retain a vestigial nucleus. Some species of green algae, particularly of genera Trebouxia or Pseudotrebouxia, can be found in symbiotic associations with fungi to form lichens. In general, the fungal species that partner in lichens cannot live on their own, while the algae species is often found living in nature without fungus (Wikipedia, November 2008).

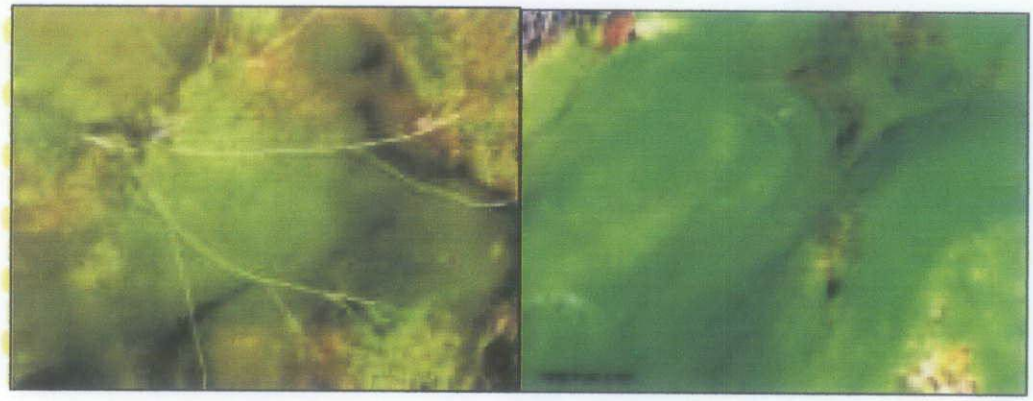


Figure 3: Green algae

2.4 Aquatic plants

Aquatic plants also called hydrophyitic plants or hydrophytes are plants that have adapted to living in or on aquatic environment. Because living on or under the water surface requires numerous special adaptations, aquatic plants can only grow in water or permanently saturated soil. Aquatic plants provide protection and spawning areas for the fish and other aquatic organisms, and they use up nutrients or in other words as nutrients removal agents. Besides that, they also shade sunlight that would otherwise promote the growth of unsightly algae. Aquatic plants also can use up large amounts of carbon dioxide and produce oxygen during daylight hours through the process of photosynthesis (Cook, 1974).

Aquatic plant can be broken down into three categories as shown in Table 1 (Cook, 1974):

Table 1: categories of aquatic plants

Categories	Aquatic plants
Floating plants	water hyacinth, water lily, water lettuce, lotus, etc
Submerged plants	elodea and hornwort
Marginal/ blog plants	cattail, sweet flag, rush and iris

All plants will need additional nutrients to have lush growth and stimulate flowers. The addition of unnecessary nutrients to the water will promote algae blooms. Potted plants must be provided with the correct balance of nutrients to obtain complete growth and colorful flowers (Cook, 1974).

2.4.1 Water hyacinth (*Eichhornia crassipes*)

Water hyacinth is one of the worst weeds in the world--aquatic or terrestrial. It took 100 years to place water hyacinth under maintenance control after it was introduced into the

U.S. Water hyacinth is fast growing perennial aquatic macrophytes. It is a member of pickerelweed family (*Pontederiaceae*) and its name *Eichhornia* was derived from well known 19th century Prussian politician, J.A.F Eichhorn. This tropical plant spread throughout the world in late 19th and early 20th century. Nowaday, it is well known for its reproduction potential and as a plant that can double its population in only twelve days. Water hyacinth is also known for its ability to grow in severe polluted waters (ecy website, July 2008).

Water hyacinth, as in Figure 4, is aquatic plant with rounded, upright and shiny green leaves, and lavender flowers similar to orchids. Individual rosette is erect and free floating with numerous stolons. Each one carries six to eight spirally arranged succulent leaves that are produced sequentially on a short vertical stem. Root system of water hyacinth is dark blue in colour with numerous stolons. New plants are formed at the end of these stolons. Water hyacinth usually can reach up to 1.5m or more in height if were measured from flower top to root top. When it is grown in wastewaters, this plant is smaller and it often reaches heights no more than 0.5m to 1.2 m (Nesic and Jovanovic, 1996).

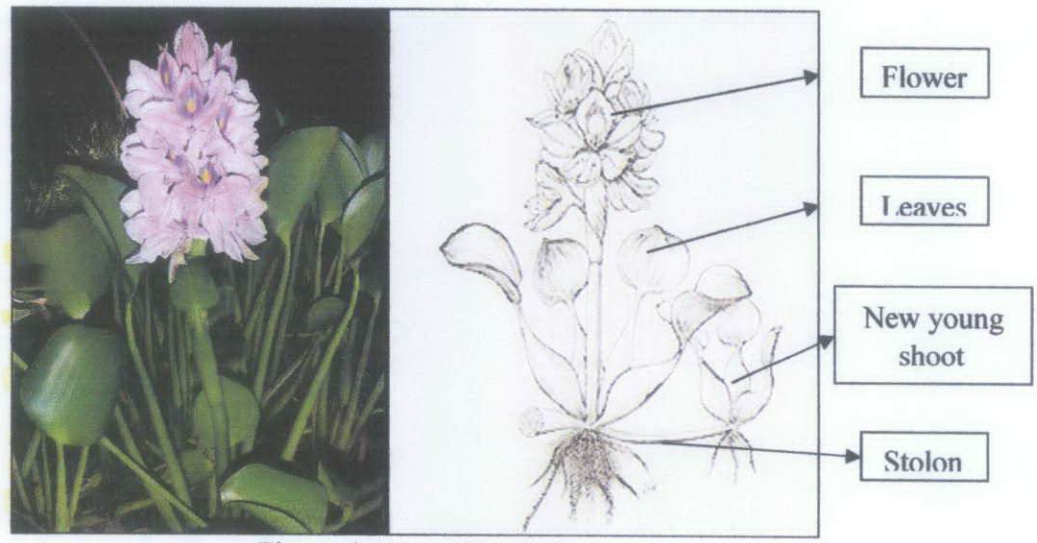


Figure 4: Water Hyacinth

2.5 Phytoremediation

2.5.1 Phytoremediation definition

Phytoremediation is a promising cleanup technology for contaminated soils, groundwater, and wastewater that is both low-tech and low-cost. It is defined as the engineered use of green plants (including aquatic microbes, grasses, forbs, and woody species) to remove, contain, or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in soil or water. Phytoremediation is a method that can reduce remedial costs, restore habitat, and clean up contamination in place rather than entombing it in place or transporting the problem to another site (Zynda, 1994).

The definition of the six types of phytoremediation and their application is listed below in Table 2 (Zynda, 1994):

Table 2: Phytoremediation types and applications

Types	Applications	Plant Species used
Phytoaccumulation or Phytoextraction	• Uptake and translocation of metal contaminants in the soil by plant roots. • Hyperaccumulators plant is capable to absorb large amount of metals compared to other plant species.	• Agrostis Castellana • Brassica Juncea • Viola Spp. • Cerastium
Phytodegradation Or Phytotransformation	• Breakdown of contaminants through metabolic process within the plant. • Pollutants are degraded, used as nutrients and incorporated into the plant tissues. • Metabolic intermediate or end products are re-released to the environment depending on the contaminants and plant species.	• Betula Pendula • Liquidambar Styraciflua • Populus Spp. • Rosa Spp. • Salix Spp. • *Eichhornia crassipes**

Phytostabilization	• Immobilize the contaminants in the soil and groundwater through adsorption and accumulation by roots. • Can reduce the mobility of contaminant and prevent migration to the groundwater or air. • Can be used to re-establish a vegetative cover at sites due to high metal concentrations.	• hybrid poplar • willow • cottonwood • aspen
Phytovolatilization	• Uptake and transpiration of contaminants by a plant. • Release of the contaminants to the atmosphere from the plant. • Contaminants will pass through the plants to the leaves and volatilize into the atmosphere at low concentrations.	• Bermuda • sorghum • fescue • poplar • willow • cottonwood • aspen
Rhizodegradation or Phytostimulation, Rhizosphere or biodegradation	• Breakdown of contaminants through microbial activity by the presence of the rhizosphere. • Microorganism consumes and degrades organic substances for use as nutrients. • Certain microorganism can degrade substances such as fuels and solvents that are hazardous to human. • Natural substances releases by the plant roots such as sugar and alcohols act as nutrient sources for the soil microorganisms.	• Agropyron Smithii • Bouteloua Gracilis • Salix Spp. • Morus Rubra • Trifolium Repens • Trifolium Pratense
Rhizofiltration	• Adsorption or precipitation of contaminants onto plant roots. • The plants are raised in greenhouse hydroponically. • The plants are harvested and disposed as the roots become saturated with contaminants.	• Brassica Juncea

* Water Hyacinth (*Eichhornia crassipes*) is categorized in phytodegradation and phytotransformation process.

2.5.2 Phytoremediation plant selection

The most important factor in implementing a phytoremediation is selecting an appropriate plant. This is often done by considering previous applications and research. The final plant choice will be influenced by the condition of the site which will affect the plant growth. In order to select the most appropriate plant, a list of potentially beneficial plants for remediation should be prepared first. (U.S EPA, 2000)

Plants are selected according to the application and the contaminants of concern. For phytotransformation of organic compounds, the vegetation should be fast growing and hardy, easy to plant and maintain, utilizes a large quantity of water by evapotranspiration and transforms the contaminants of concern to non-toxic or less toxic products. The economic success of phytoremediation largely depends on photosynthetic activity and growth rate of plants (Huilong and Xiangjuan, 2005).

Water hyacinth has the potential to cleanup various wastewater due to its fast growth and large biogas production. Inorganic contaminants such as nitrate, ammonioum and phosphorous, as well as heavy metal can be removed efficiently by water hyacinth through uptake and accumulation (Huilong and Xiangjuan, 2006). Nitrate and phosphorus removal by water hyacinth is said to be great during summer as compared to winter. Among all aquatic plants used for phytoremediation studies, water hyacinth is the most efficient macrophytes in treating wastewater. This large-leaf floating plant can enhance the nutrient removal or alter the physic-chemical environment (Freddy and De Busk, 1985).

2.5.3 Advantages and disadvantages of phytoremediation

When using phytoremediation, there are many positive and negative aspects to consider. The advantages and disadvantages are as in Table 3 (U.S EPA, 2000):

Table 3: Advantages and disadvantages of Phytoremediation

Advantages	Disadvantages
The cost of the phytoremediation is lower than the traditional processes	Phytoremediation is limited to the surface area and depth occupied by the roots.
The plants can be easily monitored	slow growth and low biomass require a long-term commitment
The possibility of the recovery and re-use of valuable metals	The survival of the plants is affected by the toxicity of the contaminated land and the general condition of the soil.
It is the least harmful method because it uses naturally occurring organisms and preserves the natural state of the environment.	Possible bio-accumulation of contaminants which then pass into the food chain, from primary level consumers upwards.

One major concern with phytoremediation is the possible effects on the food chain. For example vegetation is used to absorb toxic or heavy metals and moles or voles eat the metal contaminated plants. The predators of the moles or voles then become victims of intoxication. All though the possibilities of such scenarios are being looked at, more fieldwork and analysis is necessary to understand the possible effects phytoremediation can have (Zynda, 1994).

2.6 Water hyacinth plant uptake

Growth of water hyacinth is primarily dependent on ability of plant to use solar energy nutrient composition of water, cultural methods and environmental factor. Based on previous study, plant growth is described in two ways: first is by reporting the percentage of water surface covered of a period of time, the second and more useful method is by reporting the plant density in units of wet plant mass per unit of surface area (Nesic and Jovanovic, 1996).

2.6.1 Nitrogen removal process

Plant uptake of nitrogen is one of the processes involved in the removal of N from water hyacinth lagoons. Removal of N through plant uptake will depend on the growth rate of the plant, culture density and environmental parameters such as solar radiation and temperature. Hyacinth plants are capable of assimilating both ammonium and nitrate, however as with many aquatic plants there is a preferential uptake of ammonium over nitrate, even though both ions are present in the wastewater at the same time (Reddy & Tucker, 1983).

Table 4: Nitrogen transformation influenced by microbial respiration in an aquatic macrophyte wastewater treatment system (Reddy, 1985)

Respiration		Nitrogen transformation
Aerobic	Ammonification	Org - N ---------> NH_4^+
	Immobilisation	NH_4^+ ---------> Org - N
	Nitrification	NH_4^+ ---------> NO_3^-
Facultative anaerobic	Denitrification	NO_3^- ---------> N_2O ---------> N_2
	Ammonification	Org - N ---------> NH_4^+
	Immobilisation	NH_4^+ ---------> Org - N
Anaerobic	Dissimilatory NO_3^- reduction	NO_3^- ---------> NH_4

Table 4 gives the various nitrogen transformations which take place within an aquatic-macrophytes based treatment system. Nitrogen transformations include: mineralisation (organic N to ammonium), immobilisation (ammonium and nitrate to organic N), nitrification (ammonium to nitrate), volatilisation and denitrification (nitrate to nitrous oxide and nitrogen gas) (Sooknah, 1999).

Nitrification involves the biological oxidation of ammonium to nitrate. The bacteria involved are chemo-autotrophic and utilize oxygen as their electron acceptor, while ammonium is used as their substrate. In a floating aquatic macrophytes system, nitrification potentially occurs in the water column and in the rhizosphere under low

organic carbon concentration. Since oxygen concentration of the water under floating plants is usually low, nitrification rates in these systems can be limited by oxygen supply (Sooknah, 1999).

Denitrification occurs in the absence of oxygen, when facultative anaerobic microorganisms utilize nitrate as a terminal electron acceptor during their respiration. During this process, nitrate is reduced to gaseous end products such as nitrous oxide and nitrogen gas. Denitrification can potentially occur in the sediment, water column devoid of oxygen, and in the anoxic sites of the rhizosphere. (Metcalf & Eddy, 1991)

Comparing the effectiveness of water hyacinth (E. Crassipes) and other aquatic macrophytes, it was proved that water hyacinth is superior in removing nutrients. This was showed from a study made in comparing the percentage of reduction between E. Crassipes and S. auriculata. The maximum values for nitrogen removal in the samples containing E. Crassipes are 85% while 40% of percentage reduction for S. auriculata. These result showed that E. Crassipes is more efficient in removing nitrogen (petrucio and Esteves, 2000).

2.6.2 Phosphorus removal

Phosphorus removal from water hyacinth lagoons is due to plant uptake, retention by the underlying sediments, and precipitation in the water column. Since phosphorus is retained by the system, the ultimate removal from the system is achieved by harvesting the plants and removal of sediment (Sooknah, 1999).

Studies showed a luxury uptake of phosphorus for water hyacinth. However, high concentration of nutrients may reduce the adsorption and growth rates of the plants. Regarding the percentage of reduction, the maximum values are 97% in the samples with water hyacinth. These result confirm the water hyacinth is more efficient in the removal of nutrients other than other aquiatic plants tested (Petrucio and Esteves, 2000).

CHAPTER 3

METHODOLOGY

There are some procedures developed in order to carry out this project. This is to ensure that the project flow is smooth and can be accomplish within the given period.

3.1 Research

The research involved in this scope of study are the research on the process of phytoremediation, application of phytoremediation, reactor tank design and construction, plant selection for phytoremediation and effluent measurements. Such information was obtained from journals, papers, website-related topic, and text books. Once enough information was obtained, the flowrate of influent will be determined using the detention time found from research.

3.2 Health, Safety and Environment (HSE) Evaluation

Health, safety and environmental (HSE) awareness is important in order to prevent accidents, increase work productivity, prevent loss event, produce healthy student and public, and prevent of properties damage. This method was applied before any experiments or works process.

3.2.1 Identifying workplace hazard

Workplace hazard identification was applied by developing a hazard check list through inspection of unsafe act or condition. An observation of workplace hazard was conducted by examining material safety data and products label. A job safety analysis

between the student and lecturer/ technician is important in order to identify any hazard that might happen during the work process.

3.2.2 Apply safety and hazard procedure

Hazard is divided into three categories: physical hazard, chemical hazard and biological hazard. Physical hazard was prevented by wearing safety equipments during the experiment process and by seeking guidance from the technician/ lecturer when dealing with any explosive equipment. Since this project was involved with certain chemical substances, the safety data should first be identified and the safety precaution should be applied. Since municipal wastewater contains bacteria, therefore it should be handled with care as it could cause infection if handling with naked hand. Therefore, protection such as glove and mask should be worn whenever dealing with it.

Figure 5: Safety precaution signs in Laboratory

3.3 Sample gathering and reactor tank setup

The municipal wastewater sample was manually gathered from UTP's sewage treatment plant (STP) while water hyacinths are gathered from local lake around Tronoh, Perak. Two reactor tanks will be used for the entire experimental period. Both reactor tanks were obtained from the previous study. One reactor tank was used for pilot test at which it will be filled with water hyacinths while the other tank was used for control purpose where as no water hyacinths were planted in it.

3.3.1 Reactor tank Setup

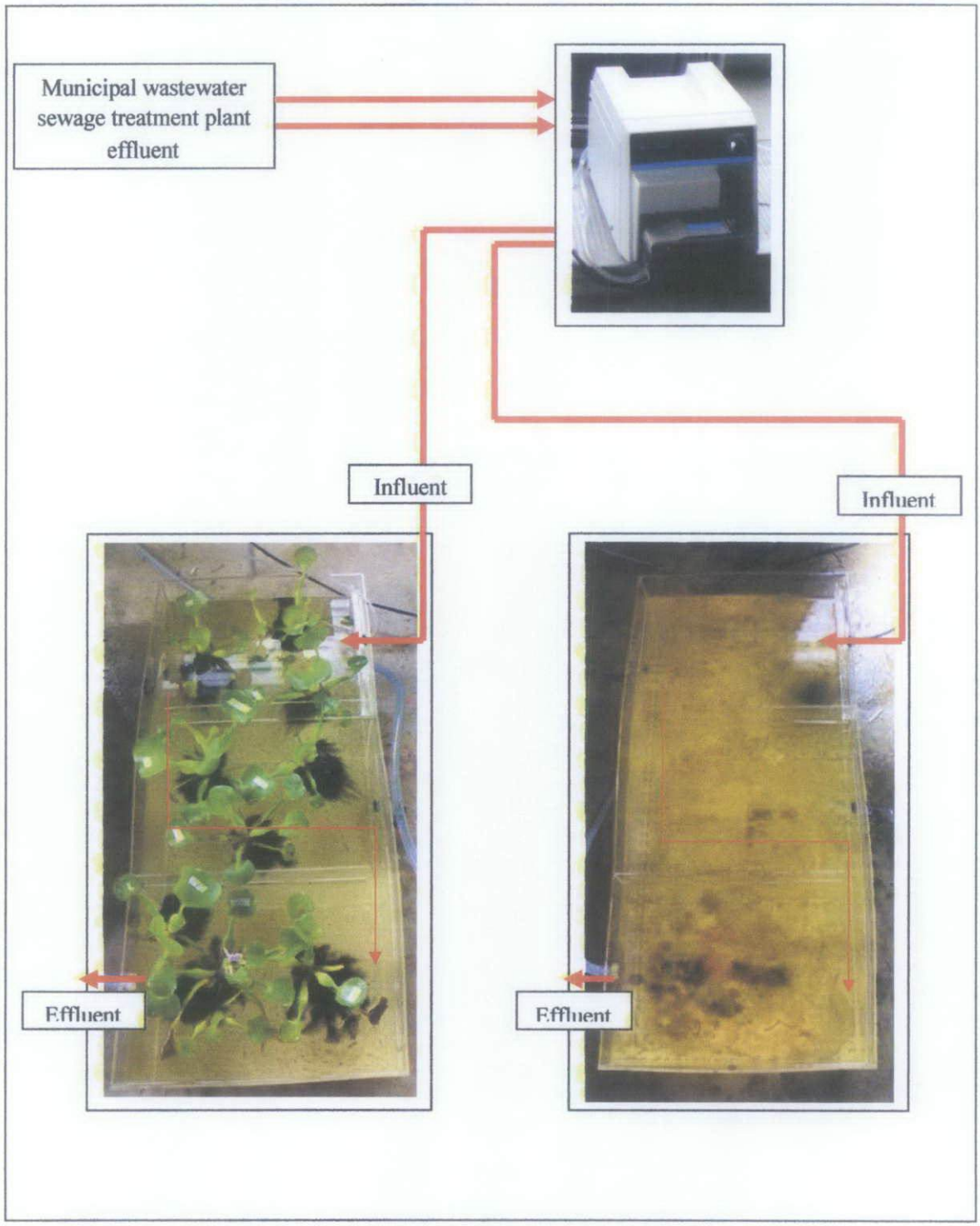


Figure 6: Experimental and reactor tanks setup

Figure 6 shows the reactor tank setup for this study. Both reactor tank was constructed using 5 mm transparent PVC with dimension of 90 x 40 x 25 cm (Length x Width x Height). Three compartments with one sampling point for each compartment were constructed on the side of the tank. The three sampling points, namely W-T1, W-T2, W-T3 for wetland reactor tank and C-T1, C-T2, C-T3 for control reactor tank, were attached with 5 mm plastic tube in order to ease the sampling operation. Three water hyacinths were cultivated in each compartment in wetland tank while no plants were placed in control tank as it was used for control purposes.

Two plastic tubes of 5 mm in diameter were used to channel the effluent municipal wastewater directly from the drain outside the experimental house. One tube was for wetland tank while the other one was used for the control tank. Each plastic tube was 6 m in length and they were sprayed with black spray in order to prevent algae growth in the channeling tubes. The channeled tubes were then connected to the Master Flexx pump with one end of the pump was connected to the effluent municipal wastewater input while the other end was connected to the reactor tank influent point. The flowrate of the pump was set to 12 mg/L.

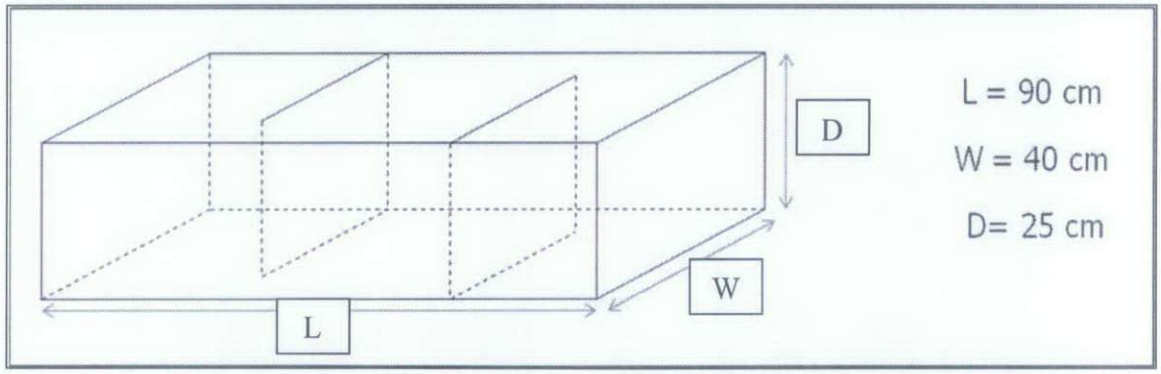


Figure 7: Reactor tank dimension

3.4 Water hyacinth growth, development and reproduction of plant

One week of acclimatization period was set to stabilize the water hyacinth and the experiment process was start right away after end of the acclimatization period. Total

detention time for municipal wastewater to travel from influent of the reactor tank was set to 6 days with 2 days of detention time for one compartment.

Three young individual of water hyacinths of the same size were placed in each compartments of the pilot tank. To monitor the growth of water hyacinth, the plant density in units of wet plant mass per unit of surface area is reported. Before weighing the water hyacinth, they should first be manually dried for 5 minutes in room temperature. After 5 minutes, weight of each water hyacinth is weighed and recorded. Finally, all plants were returned to their respective compartments.

This aquatic plant can reproduce in both generative and vegetative ways. New plants can be produced from seeds or they represent clones derived from stolon elongation due to division of auxiliary meristems of mother plant. The development of young shoot and reproduction of the plants were recorded in every sampling day.

3.5 Field experimental process

After water hyacinth has been acclimatized, the field experiment should start by releasing the effluent municipal wastewater from inlet pipe with specified flowrate (Q=12 L/day). The wastewater samples was collected using sampling bottle as shown in Figure 8 and were measured to determine the initial COD, ammonia, phosphorus and nitrate. Water samples from each compartment were collected at every 2 days for a total of 24 days of sampling day. Plant sample were weighed and the observation of their plant production is conducted at every sampling day in order to determine the growth data.

Figure 8: Sampling bottles

3.6 Measurement of parameters

3.6.1 Measurement of chemical oxygen demand (COD)

The COD measurement is a test to determine the amount of chemical oxygen demand in a sample after the sample being treated. The test was conducted by adding 2 ml of wastewater sample into a vial. Three vials had been prepared for each sample. The samples were heated at 150℃ for 2 hours in the heater as shown in Figure 9. The blank sample was prepared by pipetting the distilled water into the vial and heats it for 2 hours at 150°C. After the sample finished heated, wait for the samples to cool down to room temperature and the COD reading was taken using the spectrophotometer.

Figure 9: Heating of vial for COD measurement

3.6.2 Measurement of ammonia (Nessler Method)

A 50 mL cylinder was filled to the 25 mL mark with the sample. Then, the sample from that cylinder was pour into the 125 mL volumetric flask. Then the same procedures were repeated for the blank preparation by using distilled water instead the sample. After that, three drops of Mineral Stabilizer were added to each volumetric flask, and then both were shaking for several times to mix. After that, three drops of Polyvinyl Alcohol Dispersing Agent also were added to each volumetric flask, and then both were shake for several times to mix. Then, by using Tensette pipette, 1.0 mL of

Nessler Reagent was put into both volumetric flasks. The timer was started for a one-minute reaction period. After that, 10 mL of each solution was pour into a 10 mL square sample cell. When the timer expires, the blank was wiped and inserted into the cell holder of DRB 2500 device with the fill line facing right, and the reading was taken. The same procedures were repeated for another sample. Three readings were taken and calculated the average for results.

3.6.3 Measurement of nitrate

The nitrate measurement is conducted by filling up a square sample cell with 10 mL of wastewater sample. One packet of NitraVer 5 Nitrate Reagent Powder Pillow is poured into the sample cell and is stopper. The sample cell is shake for 1 minute and leave it for 5 minutes for reaction to occur. Finally, the wastewater sample cell is wiped and inserted into the cell holder as in Figure 10. Once the read button is pressed, the result in mg/L will be displayed.

Figure 10: Nitrate measurement using spectrophotometer

3.6.4 Measurement of phosphorus

The phosphorus measurement is conducted by filling up a vial (contain sulfuric acid) with 5 mL of wastewater sample. One packet of Pottasium Persulfate Powder is poured into the vial and then it is digested for 30 min at 150 ℃. After sample is cooled to room temperature, 2 mL of NaOH is added into the vial and is shake for 1 minute. The vial is

inserted into the cell holder of Spectophotometer as shown in Figure 11 and PhosVer 3 is added into the vial. The sample was shake for 5 minute to allow digestion and finally the vial is put back into the Spectophotometer. The reading of phosphorus concentration is taken.

Figure 11: Phosphorus measurement using spectrophotometer

For each experiment, three reading for each samples were tested and the average is taken as the exact value.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Influent flowrate determination

Flowrate determination is important in order to determine the required amount of wastewater sample needs for the whole experiment. Therefore, shortage of wastewater sample can be avoided. Flowrate was also used to determine the plant uptake for water hyacinth. The calculation of determining the influent flowrate is shown as in Appendix B8. The influent flowrate was controlled by a one-channel Masterflexx pump at which the pump will transfer the influent wastewater based on the specified flowrate. A 6 days of detention time was used as the reference time. After the calculation, it was found that the flowrate used for this study was 12 mg/L.

4.2 Data analysis

Initially, UTP's sewage treatment plant is discharging COD, ammonia, phosphorus and nitrate with each having an average value of 58 mg/L, 12 mg/L, 5 mg/L and 7 mg/L respectively as shown in Table 5. In every two days, the water sample in each compartment from both reactor tanks was collected and tested in order to evaluate the effectiveness of water hyacinth in treating the undesirable concentration of phosphorus, nitrate, COD, and ammonia from the municipal wastewater treatment plant effluent.

Table 5: Average concentration of Municipal wastewater effluent

Constituent	Average concentration (mg/L)
Chemical Oxygen demand (COD)	58
Ammonia	12
Phosphorus	5
Nitrate	7

4.2 Chemical oxygen demand (COD) data analysis for both reactor tanks

4.2.1 Chemical Oxygen Demand (COD) concentration for wetland reactor tank

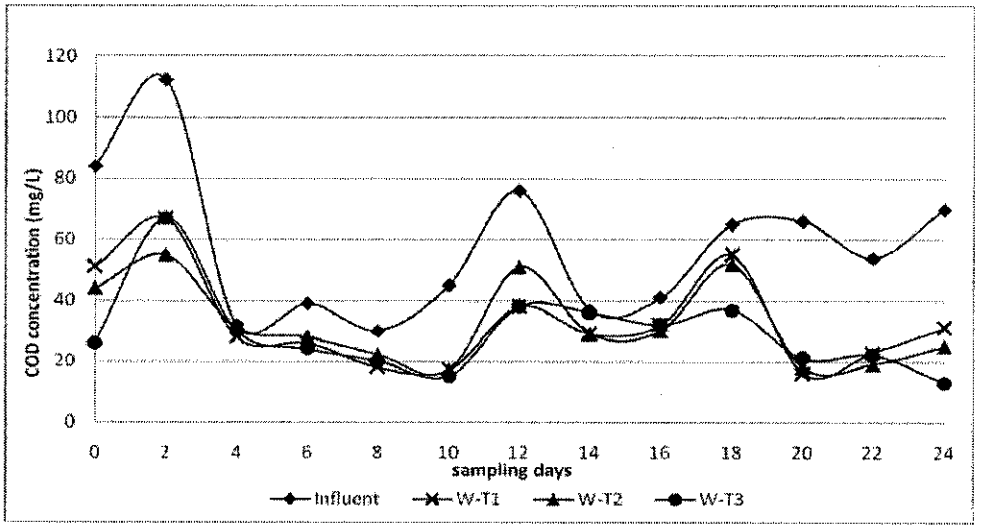


Figure 12: COD concentration vs. sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for wetland tank.

Figure 12 shows the concentration of COD for both influent and effluent sample in all three compartments in wetland tank from day 0 till day 24. The influent shows scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely W-T1, W-T2 and W-T3 show closed gap with one another, this may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the COD concentration for W-T3 shows the lowest among the other two concentrations.

The COD concentration at wetland tank ranged from 67 mg/L to 13 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in COD concentration between W-T1 and W-T2, W-T2 and W-T3, and W-T1 and W-T3.

4.2.2 Chemical Oxygen Demand (COD) concentration for control reactor tank

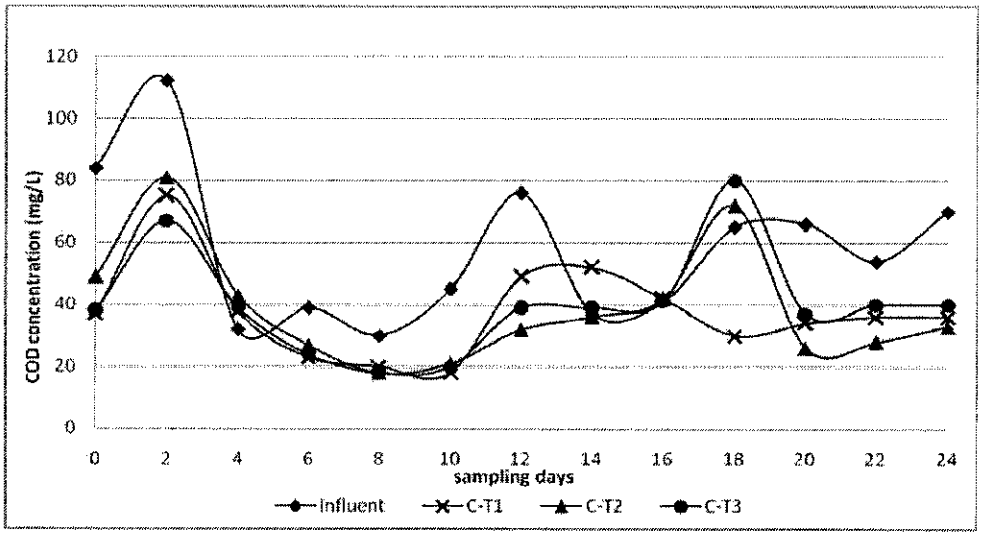


Figure 13: COD concentration vs. sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for control tank.

Figure 13 shows the concentration of COD for both influent and effluent sample in all three compartments in control tank from day 0 till day 24. The influent shows scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely C-T1, C-T2 and C-T3 show closed gap with one another at the beginning of the experiment but then they started to depart starting from day 11. The closed gap may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the COD concentration for C-T2 shows the lowest among the other two concentrations.

The COD concentration at control tank ranged from 80 mg/L to 18 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in COD concentration between C-T2 and C-T3, and C-T1 and C-T3. But there is a significant difference between C-T1 and C-T2.

4.2.3 Chemical Oxygen Demand (COD) removal efficiency for both reactor tanks at various detention times

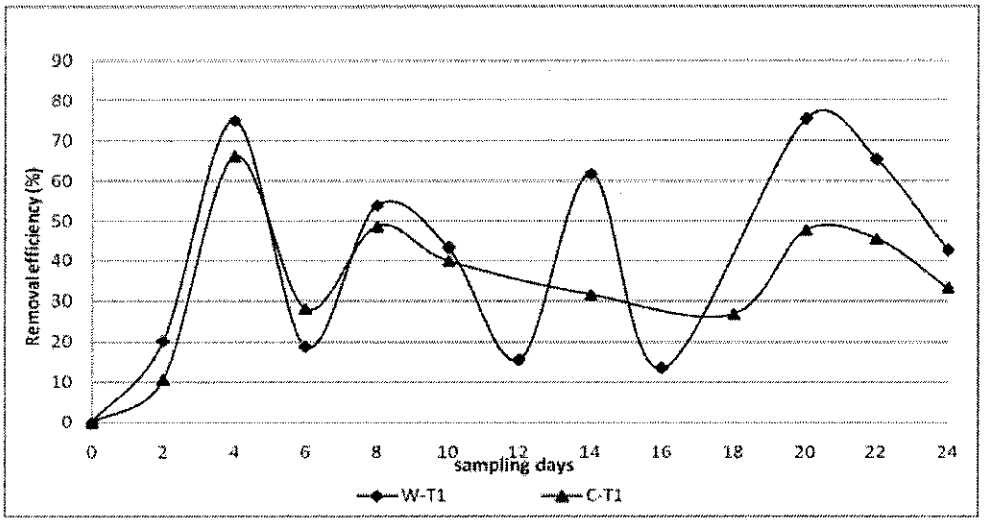


Figure 14: COD removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T1 = 2 days.

Referring to Figure 14, the COD removal efficiency for W-T1 is higher than that of C1.T1 at the end of sampling day 24. The maximum COD removal efficiency for W-T1 is 75% while the maximum COD removal efficiency for C-T1 is 66%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T1 and C-T1.

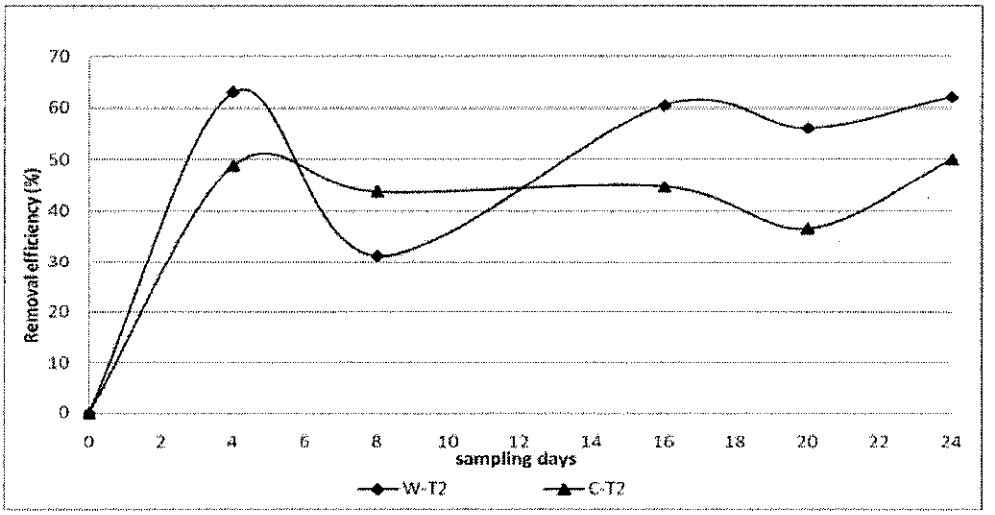


Figure 15: COD removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T2 = 4 days.

Referring to Figure 15, the COD removal efficiency for W-T2 is higher than that of C2.T2 at the end of sampling day 24. The maximum COD removal efficiency for W-T2 is 63% while the maximum COD removal efficiency for C-T2 is 50%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T2 and C-T2.

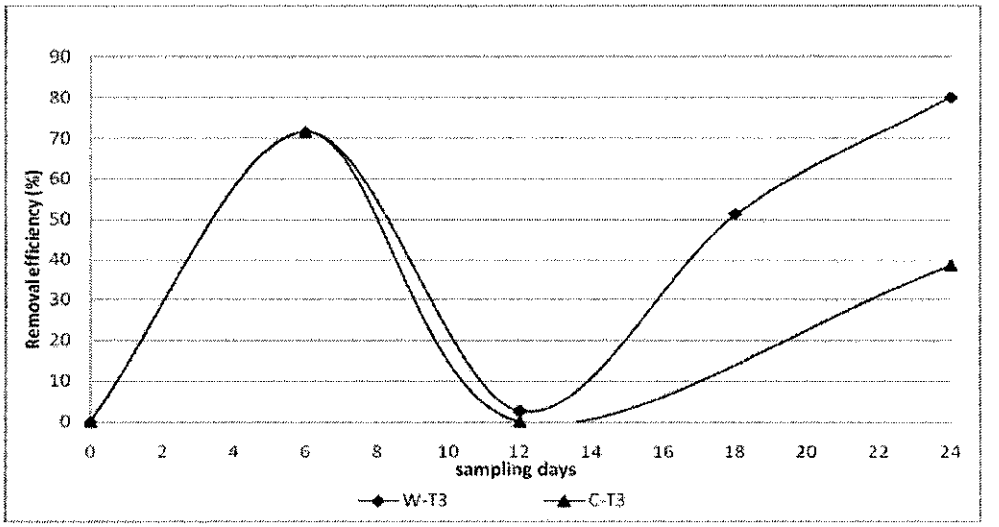


Figure 16: COD removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T3= 6 days.

Referring to Figure 16, the COD removal efficiency for W-T3 is higher than that of C3.T3 at the end of sampling day 24. The maximum COD removal efficiency for W-T3 is 80% while the maximum COD removal efficiency for C-T3 is 71%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T3 and C-T3.

4.4 Ammonia data analysis for both reactor tanks

4.4.1 Ammonia concentration for wetland reactor tank

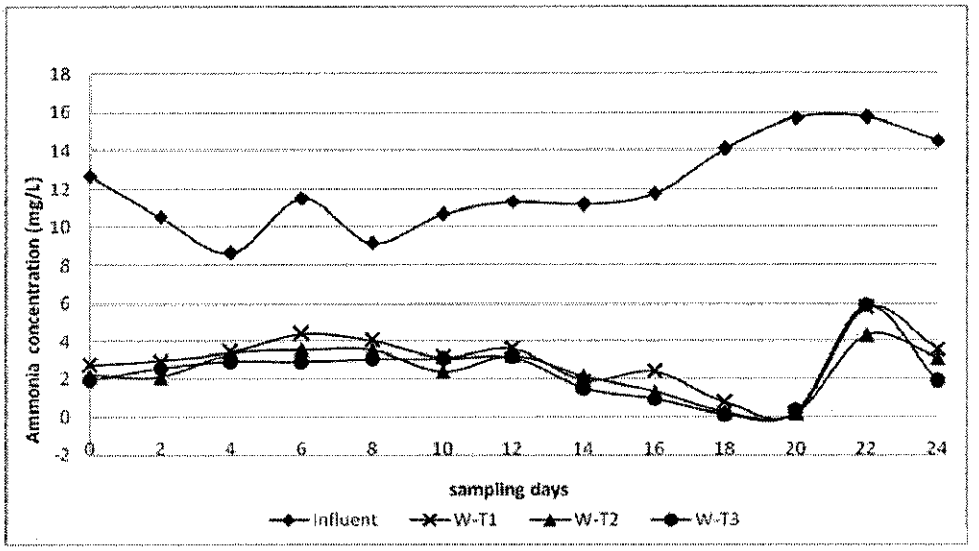


Figure 17: Ammonia concentration vs. sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for wetland tank.

Figure 17 shows the concentration of ammonia for both influent and effluent sample in all three compartments in wetland tank from day 0 till day 24. The influent shows scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely W-T1, W-T2 and W-T3 show closed gap with one another, this may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the ammonia concentration for W-T3 shows the lowest among the other two concentrations.

The ammonia concentration in wetland tank ranged from 5.87 mg/L to 0.13 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in ammonia concentration between W-T1 and W-T2, W-T2 and W-T3, and W-T1 and W3.T3.

4.4.2 Ammonia concentration for control reactor tank

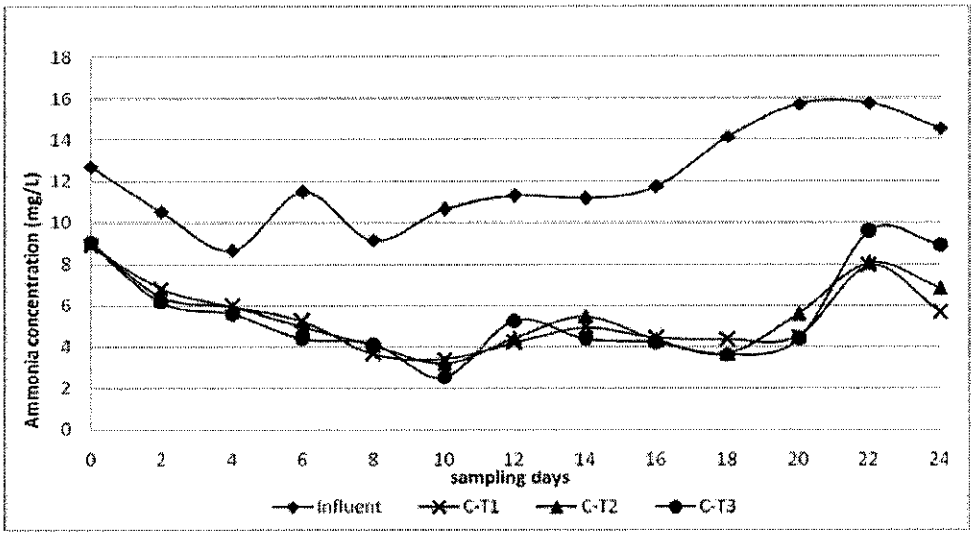


Figure 18: Ammonia concentration vs. sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for control tank.

Figure 18 shows the concentration of ammonia for both influent and effluent sample in all three compartments in control tank from day 0 till day 24. The influent shows scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely C-T1, C-T2 and C-T3 show closed gap with one another, this may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the ammonia concentration for C-T3 shows the lowest among the other two concentrations.

The ammonia concentration at control tank ranged from 9.57 mg/L to 2.53 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in ammonia concentration between C-T2 and C-T3, and C-T1 and C-T3. But there is a significant difference between C-T1 and C-T2.

4.4.3 Ammonia removal efficiency for both reactor tanks for various detention times

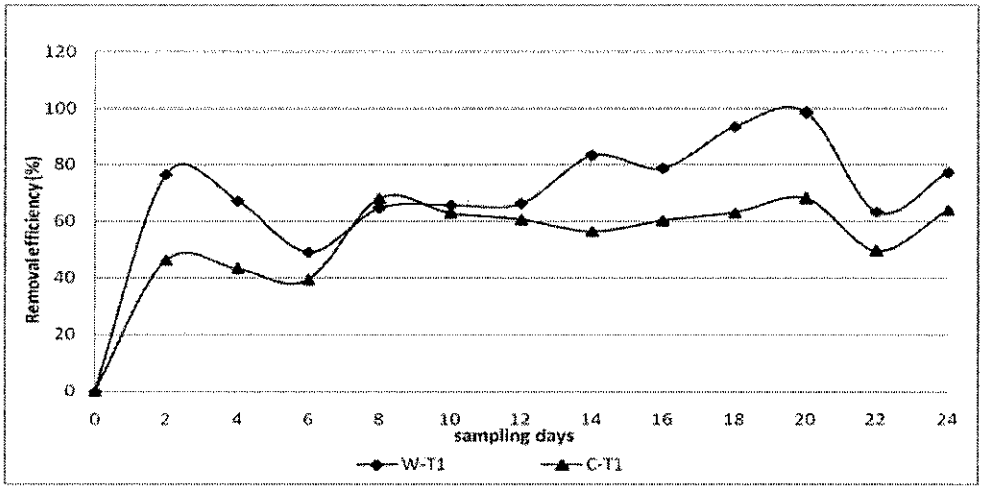


Figure 19: Ammonia removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T1 = 2 days

Referring to Figure 19, the ammonia removal efficiency for W-T1 is higher than that of C-T1 at the end of sampling day 24. The maximum ammonia removal efficiency for W-T1 is 98% while the maximum ammonia removal efficiency for C-T1 is 68%. Based on the statistical analysis conducted at 5% level of significance, there is a significant difference in COD removal efficiency between W-T1 and C-T1.

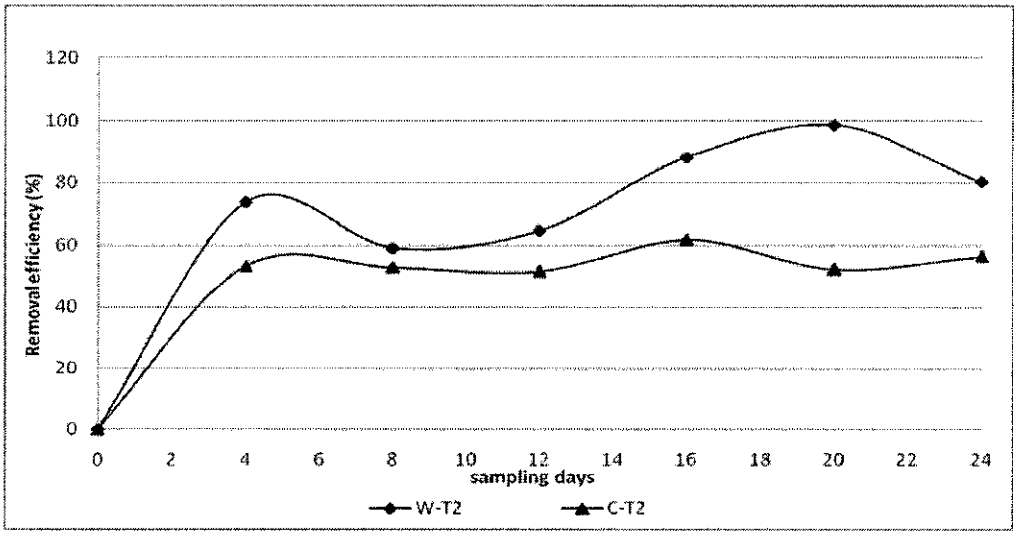


Figure 20: Ammonia removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T2 = 4 days

Referring to Figure 20, the ammonia removal efficiency for W2.T2 is higher than that of C2.T2 at the end of sampling day 24. The maximum Ammonia removal efficiency for W2.T2 is 99% while the maximum Ammonia removal efficiency for C2.T2 is 62%. Based on the statistical analysis conducted at 5% level of significance, there is a significant difference in COD removal efficiency between W-T2 and C-T2.

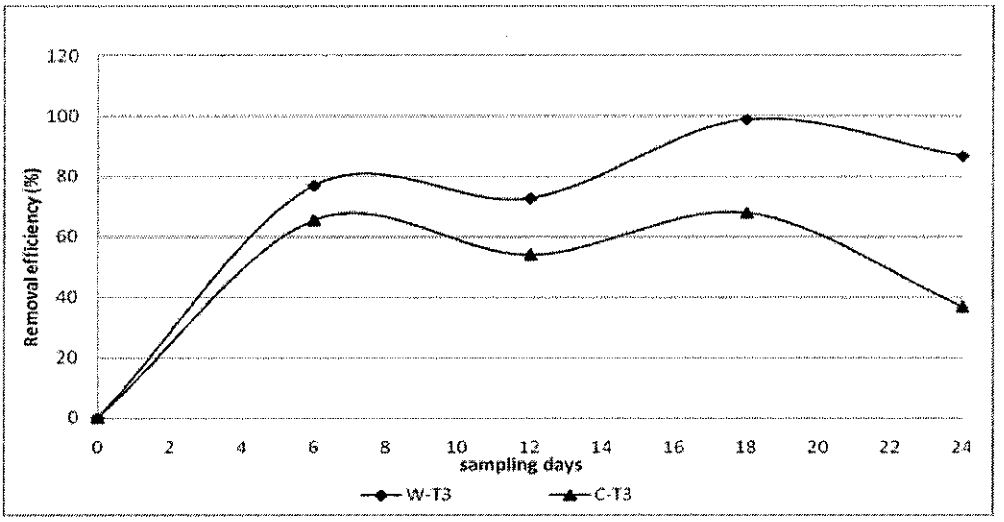


Figure 21: Ammonia removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T3 = 6 days

Referring to Figure 21, the ammonia removal efficiency for W3.T3 is higher than that of C3.T3 at the end of sampling day 24. The maximum ammonia removal efficiency for W3.T3 is 99% while the maximum Ammonia removal efficiency for C3.T3 is 68%. Based on the statistical analysis conducted at 5% level of significance, there is a significant difference in COD removal efficiency between W-T3 and C-T3.

4.5 Phosphorus data analysis for both reactor tanks

4.5.1 Phosphorus concentration for wetland reactor tank

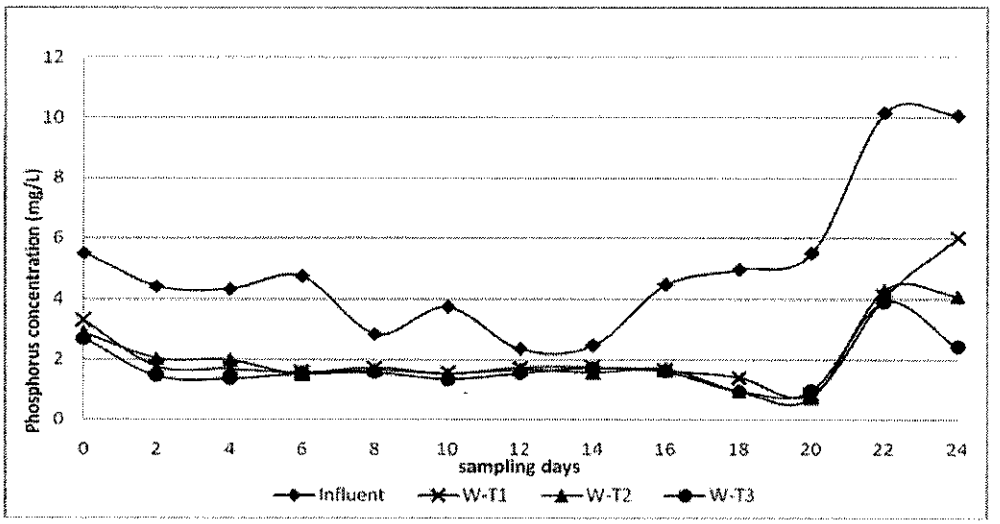


Figure 22: Phosphorus concentration vs. sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for wetland tank.

Figure 22 shows the concentration of phosphorus for both influent and effluent sample in all three compartments in wetland tank from day 0 till day 24. The influent shows uneven scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely W-T1, W-T2 and W-T3 show closed gap with one another, this may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the phosphorus concentration for W-T3 shows the lowest among the other two concentrations.

The phosphorus concentration at wetland tank ranged from 4.30 mg/L to 0.72 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in phosphorus concentration between W-T1 and W-T2, W-T2 and W-T3, and W-T1 and W-T3.

4.5.2 Phosphorus concentration for control reactor tank

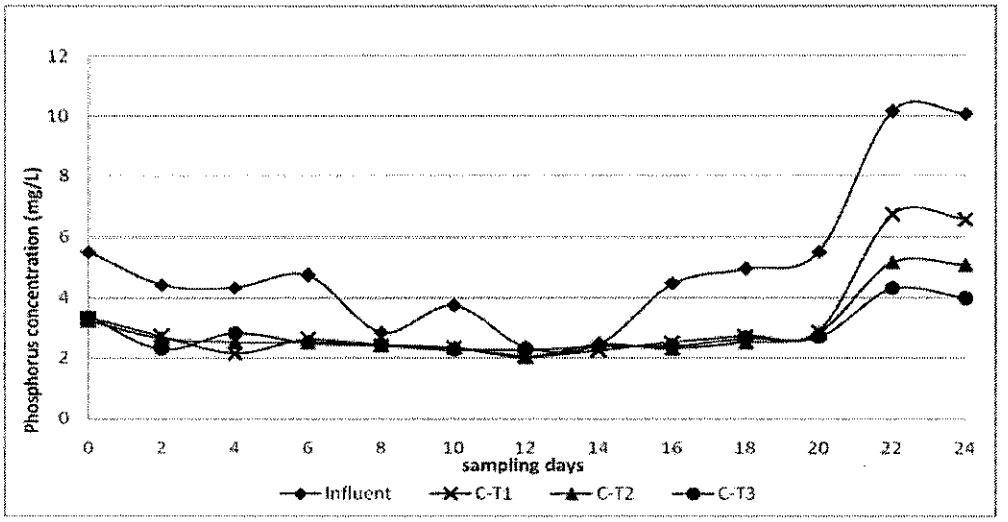


Figure 23: Phosphorus concentration vs. sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for control tank.

Figure 23 shows the concentration of phosphorus for both influent and effluent sample in all three compartments in reactor tank B from day 0 till day 24. The influent shows scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely C-T1, C-T2 and C-T3 show closed gap with one another at the beginning of the experiment but then they started to depart starting from day 22. The closed gap may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the phosphorus concentration for C-T3 shows the lowest among the other two concentrations.

The phosphorus concentration at control tank ranged from 6.72 mg/L to 2.06 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in phosphorus concentration between C-T1 and C-T2, C-T2 and C-T3, and C-T1 and C-T3.

4.5.3 Phosphorus removal efficiency for both reactor tanks for various detention times

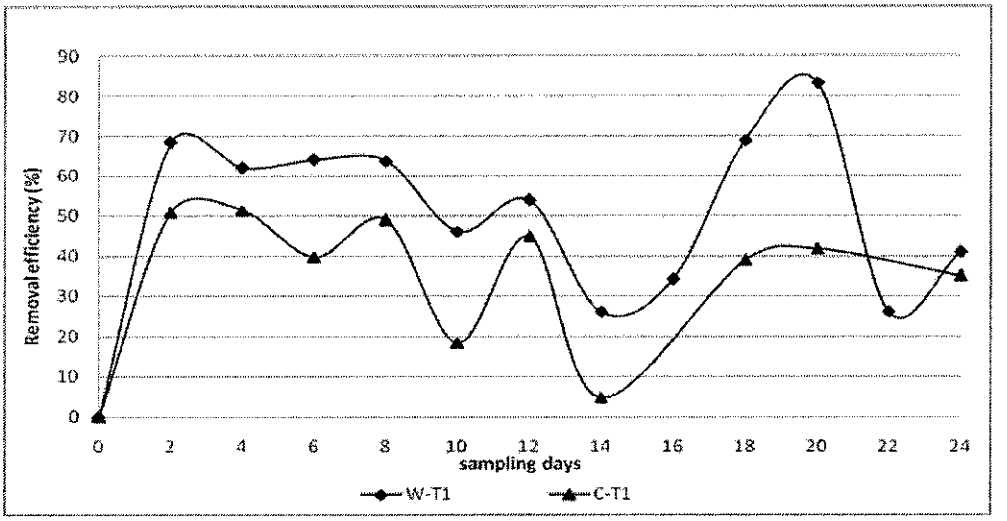


Figure 24: Phosphorus removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T1 = 2 days.

Referring to Figure 24, the phosphorus removal efficiency for W1.T1 is higher than that of C1.T1 at the end of sampling day 24. The maximum phosphorus removal efficiency for W1.T1 is 83% while the maximum phosphorus removal efficiency for C1.T1 is 51%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T1 and C-T1.

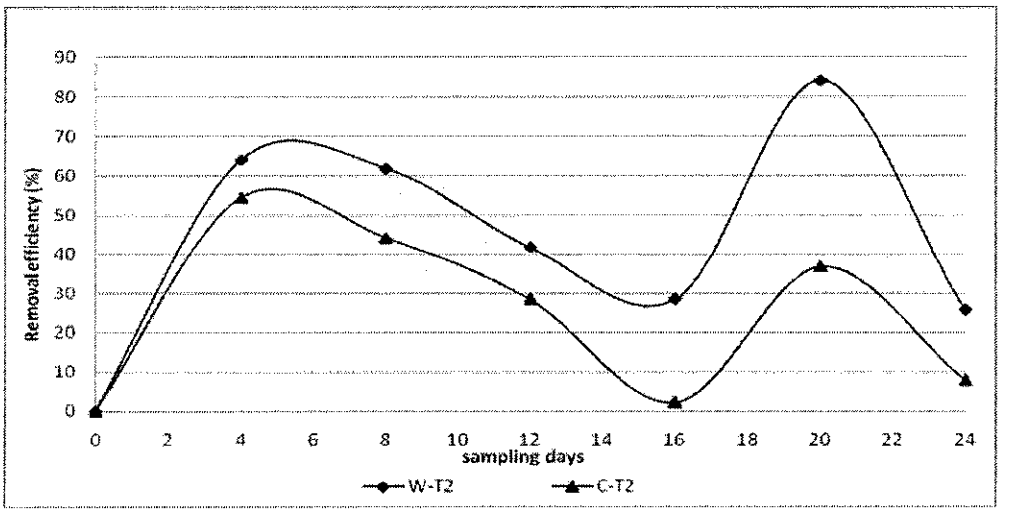


Figure 25: Phosphorus removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T2 = 4 days.

Referring to Figure 25, the phosphorus removal efficiency for W2.T2 is higher than that of C2.T2 at the end of sampling day 24. The maximum phosphorus removal efficiency for W2.T2 is 84% while the maximum phosphorus removal efficiency for C2.T2 is 55%. Based on the statistical analysis conducted at 5% level of significance, there is a significant difference in COD removal efficiency between W-T2 and C-T2.

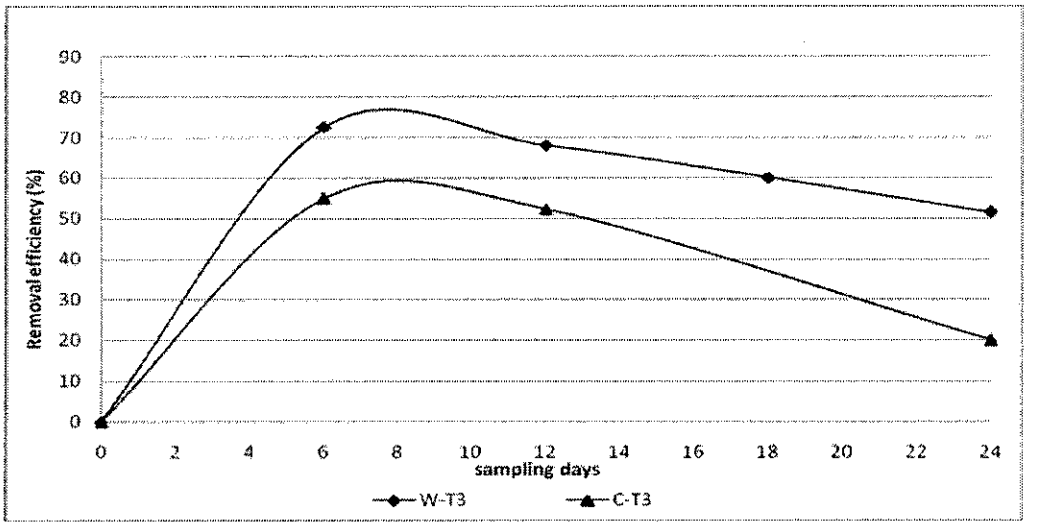


Figure 26: Phosphorus removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T3 = 6 days.

Referring to Figure 26, the phosphorus removal efficiency for W3.T3 is higher than that of C3.T3 at the end of sampling day 24. The maximum phosphorus removal efficiency for W3.T3 is 72% while the maximum phosphorus removal efficiency for C3.T3 is 55%. Based on the statistical analysis conducted at 5% level of significance, there is a significant difference in COD removal efficiency between W-T3 and C-T3.

4.5 Nitrate data analysis

4.5 1 Nitrate concentration for wetland reactor tank

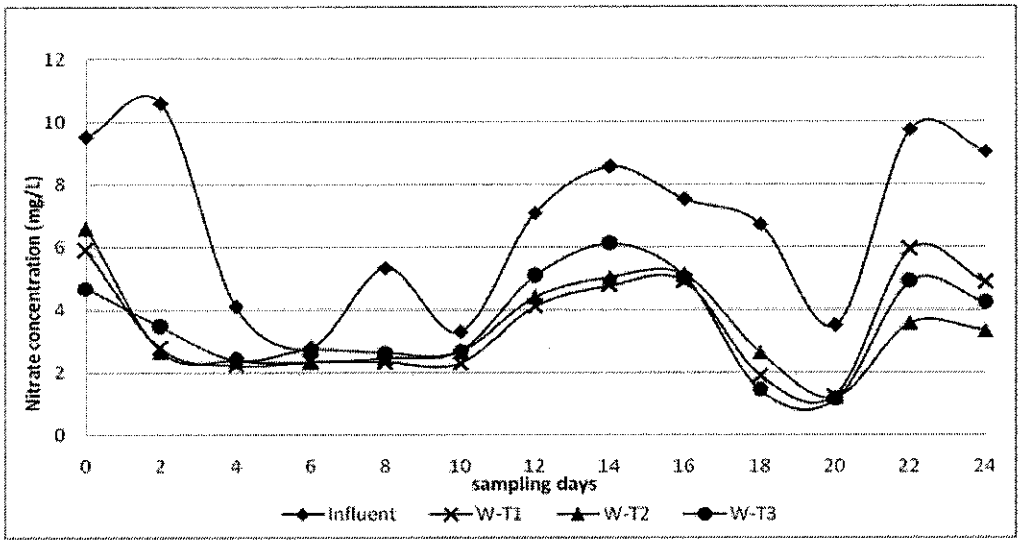


Figure 27: Nitrate concentration vs. Sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for wetland tank.

Figure 27 shows the concentration of nitrate for both influent and effluent sample in all three compartments in wetland tank from day 0 till day 24. The influent shows uneven scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely W-T1, W-T2 and W-T3 show closed gap with one another, this may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the nitrate concentration for W-T2 shows the lowest among the other two concentrations.

The nitrate concentration at wetland tank ranged from 6.6 mg/L to 1.2 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in nitrate concentration between W-T1 and W-T2, W-T2 and W-T3, and W-T1 and W-T3.

4.5.2 Nitrate concentration for control reactor tank

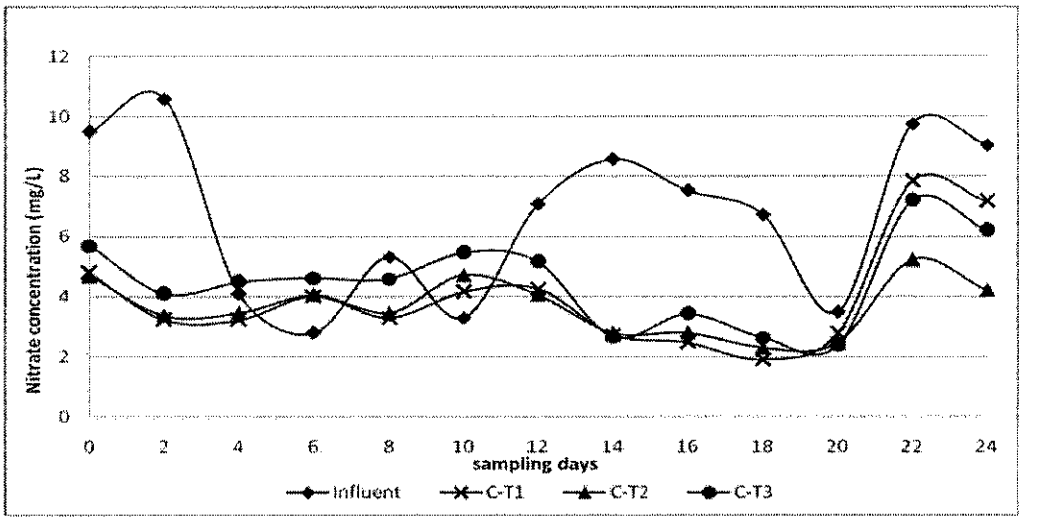


Figure 28: Nitrate concentration vs. Sampling day at Q = 12 L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for control tank.

Figure 28 shows the concentration of nitrate for both influent and effluent sample in all three compartments in control tank from day 0 till day 24. The influent shows scattered line as the concentration of municipal wastewater released from the sewage treatment plant contains various range of concentration every day.

The effluent lines, namely C-T1, C-T2 and C-T3 show closed gap with one another, this may be due to the small different in detention time of 2 days in every compartments. At the end of sampling day 24, the nitrate concentration for C-T2 shows the lowest among the other two concentrations.

The nitrate concentration at reactor tank B ranged from 7.8 mg/L to 1.9 mg/L. Based on statistical analysis at 5% level of significance, there is no significant difference in nitrate concentration between C-T1 and C-T2, C-T2 and C-T3, and C-T1 and C-T3.

4.5.3 Nitrate removal efficiency for both reactor tanks at various detention times

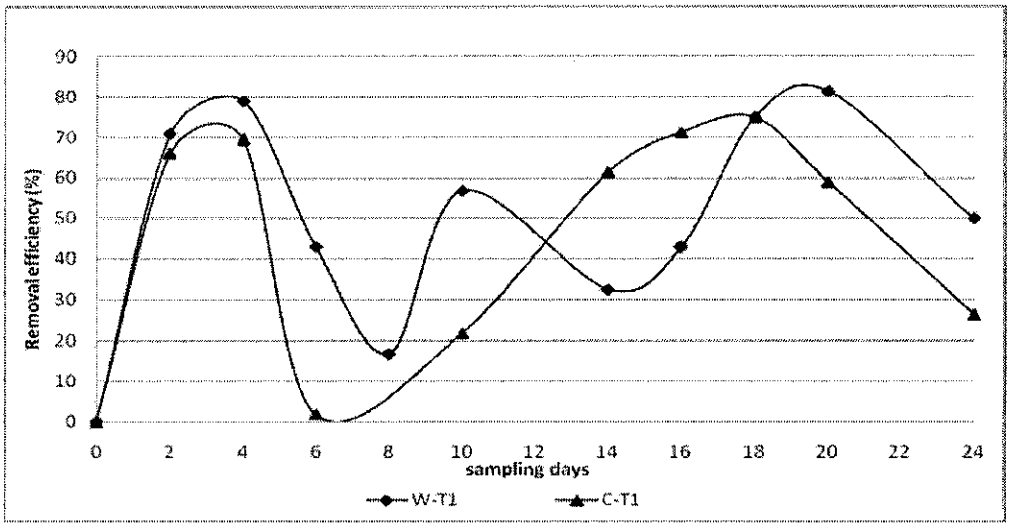


Figure 29: Nitrate removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T1 = 2 days.

Referring to Figure 29, the nitrate removal efficiency for W-T1 is higher than that of C-T1 at the end of sampling day 24. The maximum nitrate removal efficiency for W-T1 is 81% while the maximum Nitrate removal efficiency for C-T1 is 75%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T1 and C-T1.

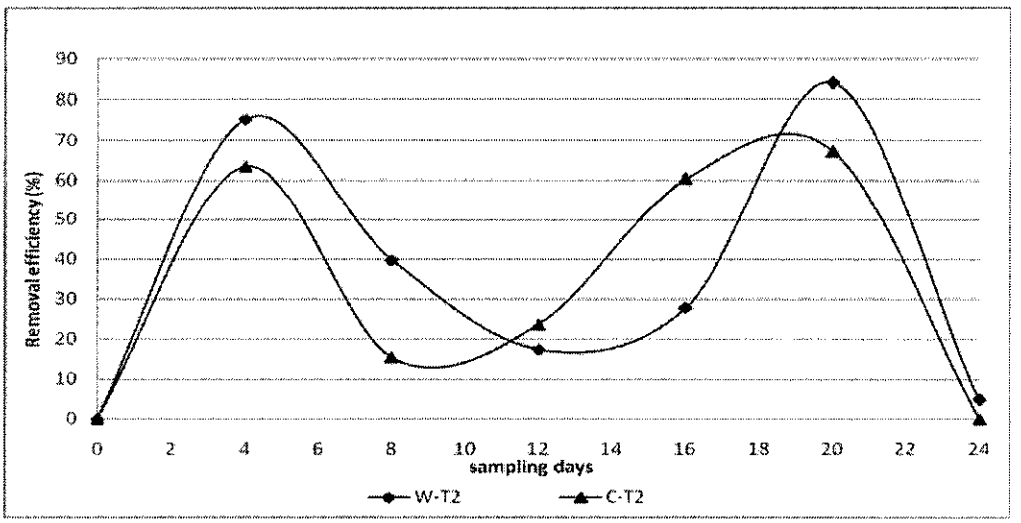


Figure 30: Nitrate removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T2 = 4 days.

Referring to Figure 30, the nitrate removal efficiency for W-T2 is higher than that of C-T2 at the end of sampling day 24. The maximum nitrate removal efficiency for W-T2 is 84% while the maximum Nitrate removal efficiency for C-T2 is 75%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T2 and C-T2.

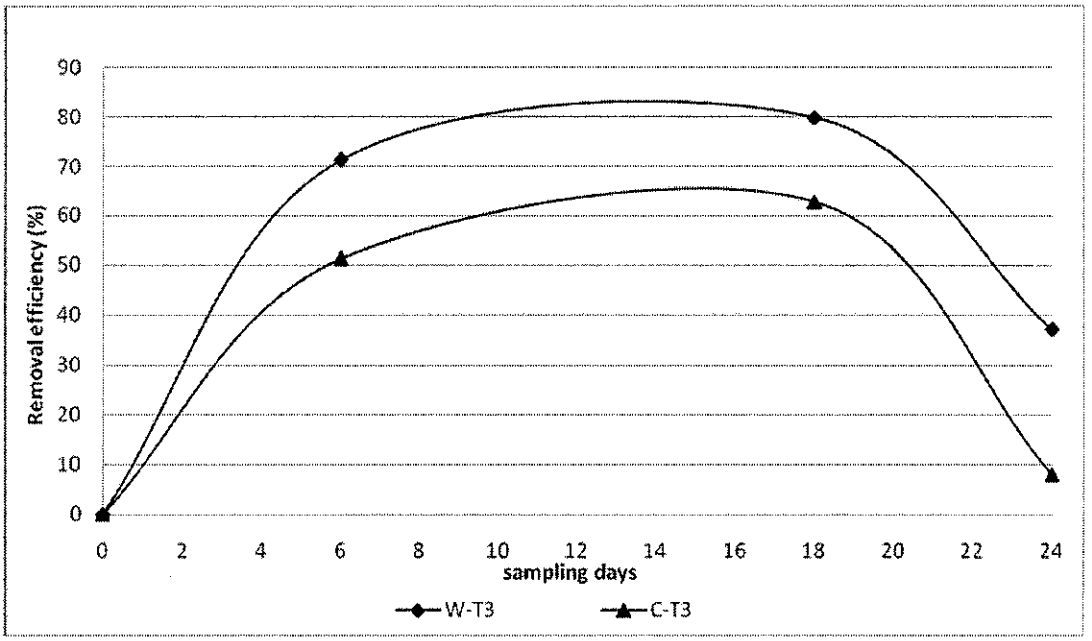
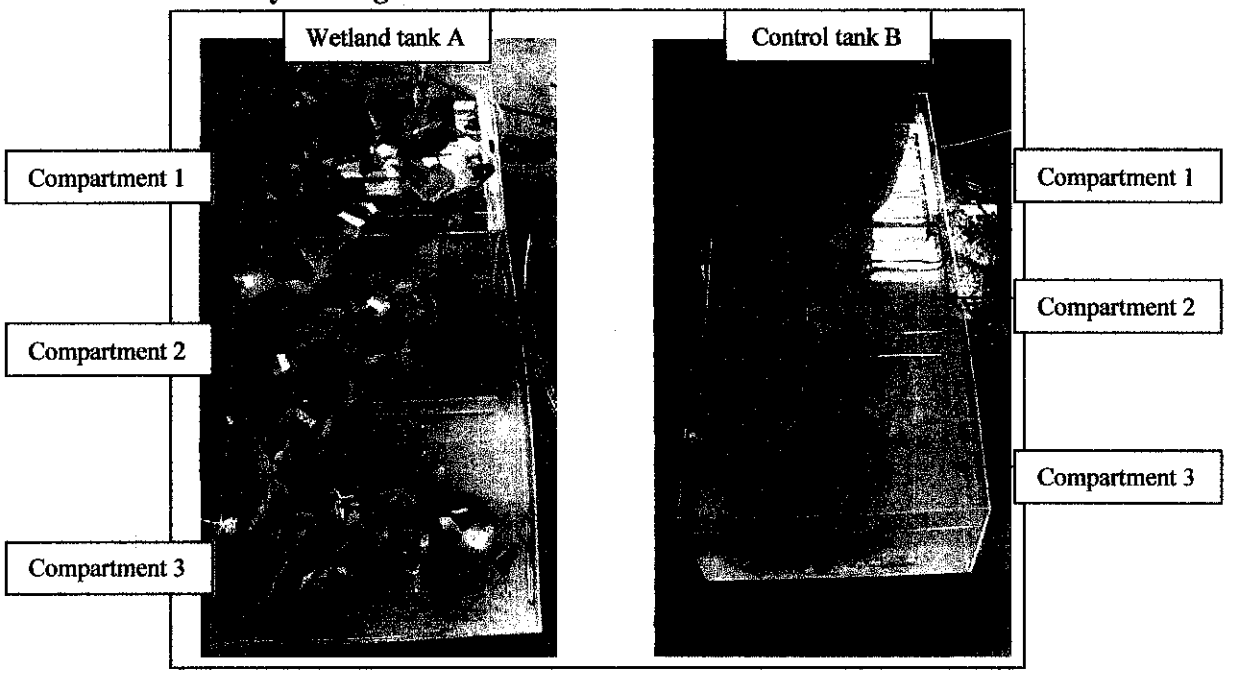


Figure 31: Nitrate removal efficiency vs. sampling day for both reactors at Q = 12 L/day at detention time T3 = 6 days.

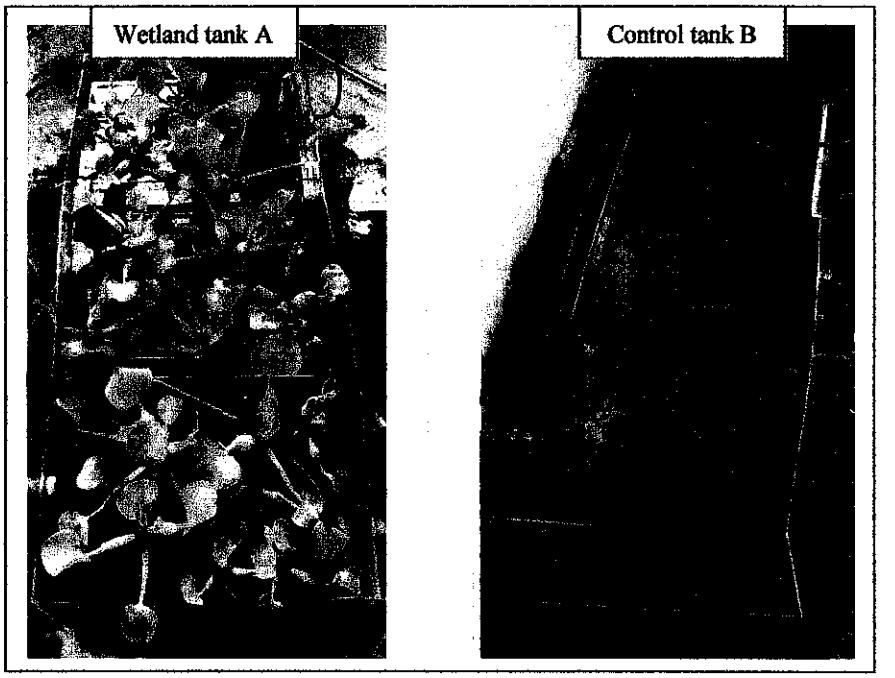
Referring to Figure 31, the nitrate removal efficiency for W-T3 is higher than that of C-T3 at the end of sampling day 24. The maximum nitrate removal efficiency for W-T3 is 80% while the maximum Nitrate removal efficiency for C-T3 is 63%. Based on the statistical analysis conducted at 5% level of significance, there is no significant difference in COD removal efficiency between W-T3 and C-T3.

4.6 Water Hyacinth growth, reproduction and data analysis

4.6.1 Water Hyacinth growth rate



At day 0



At day 24

Figure 32 : Water Hyacinth growth development at day 0 until day 24

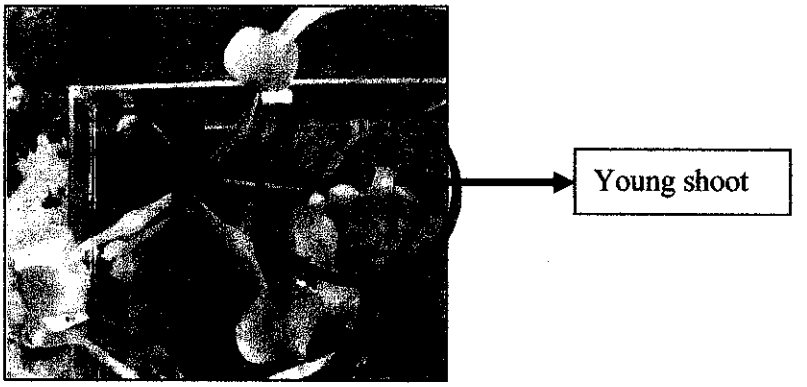


Figure 33: Young shoot development during sampling day 6 at W-T1.

Based on figure 32, the wetland tank is planted with 3 water hyacinths in each compartment while the control tank is leaved as it is without plant. After 24 days of treatment process, water hyacinth in the wetland tank has doubled their quantity at which a new young shoot starts to develop in compartment 1 at day 6.

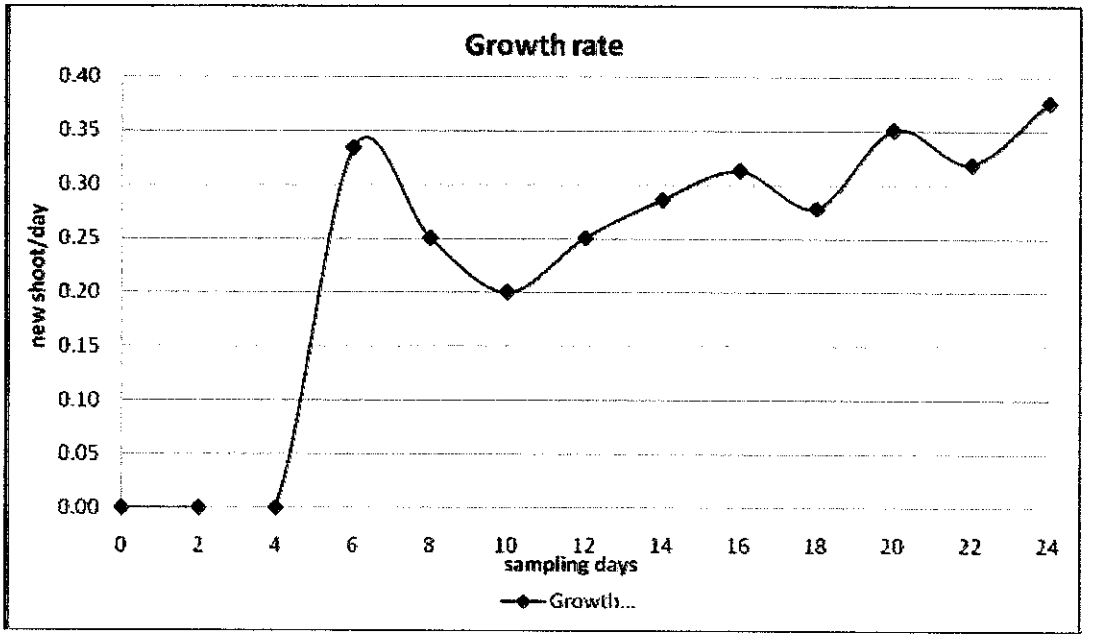


Figure 34: Growth rate versus sampling days

By referring figure 34, water hyacinth started to show development at day 6 with growth rate of 0.33 shoot/day. At the end of day 24, water hyacinth continued to grow up to 0.38 shoot/day.

4.6.2 Water Hyacinth Plant uptake

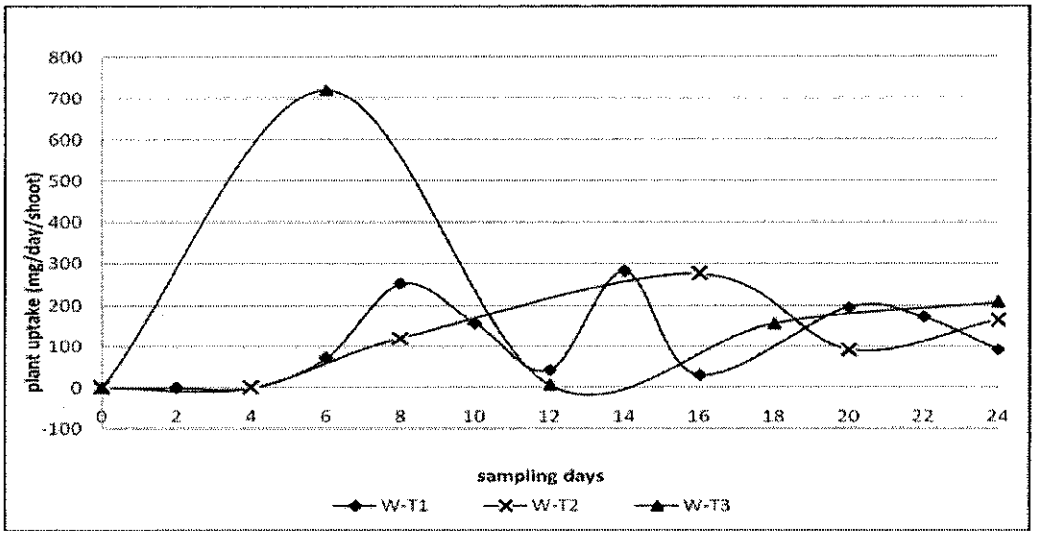


Figure 35: COD plant uptake at Q = 12L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for reactor tank A.

Based on figure 35, the COD plant uptake for W-T3 is the highest among the other compartments at the end of day 24. Starting from day 18, the plants have stabilized at which no COD uptake can be taken anymore. Therefore, it can be concluded that water hyacinth show approximately 18 days to stabilize.

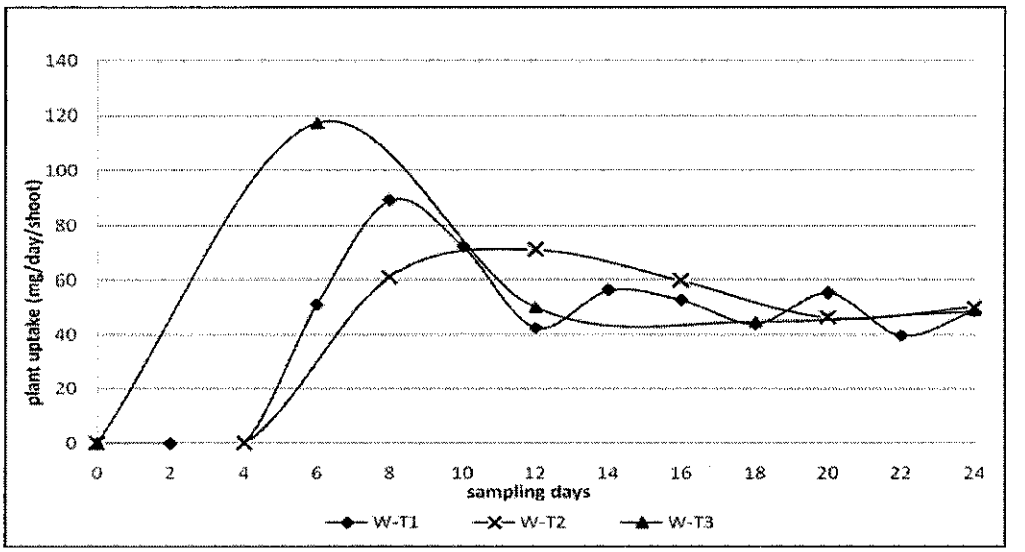


Figure 36: Ammonia plant uptake at Q = 12L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for reactor tank A.

Referring figure 36, the ammonia plant uptake for all three compartments is the same at the end of day 24. Starting from day 10, the plants have stabilized at which no ammonia uptake can be taken anymore. Therefore, it can be concluded that water hyacinth show approximately 10 days to stabilize.

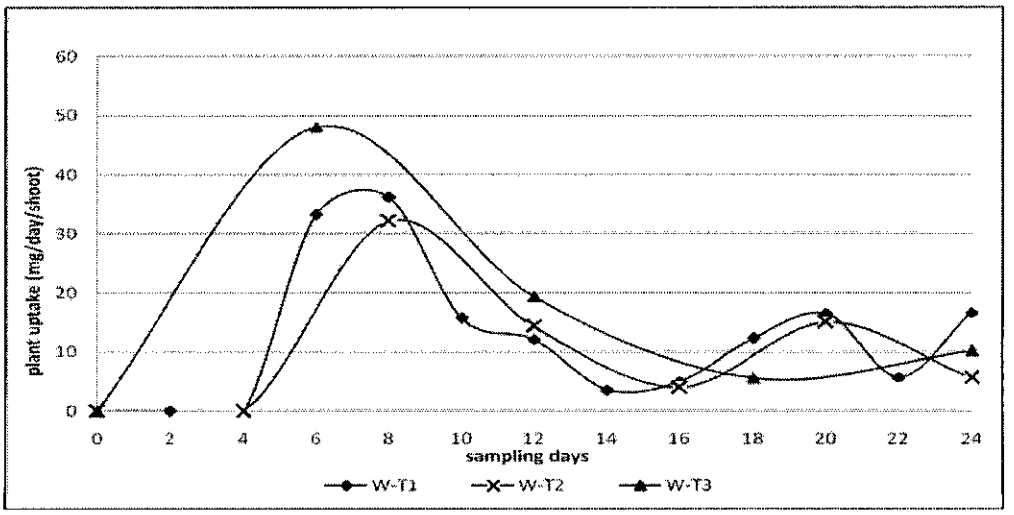


Figure 37: Phosphorus plant uptake at Q = 12L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for reactor tank A.

Referring figure 37, the phosphorus plant uptake for all three compartments is the same at the end of day 24. Starting from day 16, the plants have stabilized at which no phosphorus uptake can be taken anymore. Therefore, it can be concluded that water hyacinth show approximately 16 days to stabilize.

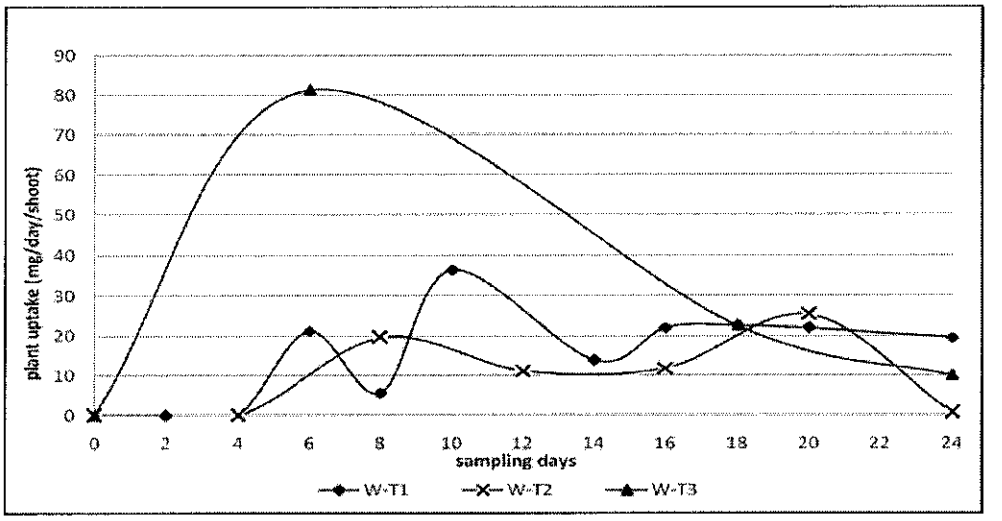


Figure 38: Nitrate plant uptake at Q = 12L/day with detention time T1 = 2 days, T2 = 4 days and T3 = 6 days for reactor tank A.

Referring figure 38, the nitrate plant uptake for all three compartments is the same at the end of day 24. Starting from day 18, the plants have stabilized at which no nitrate uptake can be taken anymore. Therefore, it can be concluded that water hyacinth show approximately 18 days to stabilize.

In conclusion, W-T1 seems to uptake the most phosphorus and nitrate since they are the first compartment to receive all the nutrients. Therefore, there is an advantage for water hyacinth in compartment 1 as they got to use up the nutrient for their growth development. This is proven as the plant size and root length in compartment 1 is bigger than other plants in the other two compartments.

Based on the plant uptake graphs for COD, ammonia, phosphorus and nitrate, it is concluded that water hyacinth start to stabilize approximately at day 10 or day 18. Thus, no further experiment is needed after the stabilizing period in order to save energy and time.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project has successfully achieved its objective and proved that water hyacinth is capable of removing COD, ammonia, phosphorus and nitrate from the municipal wastewater treatment plant effluent.

Referring to Appendix B9, the removal efficiency for COD was 49%. Based on the statistical analysis conducted, there is no significant difference between wetland tank and control tank at detention time T3 = 6 days at 5% level of significance.

Based on statistical analysis conducted, there is a significant difference for ammonia concentration between wetland tank and control tank at detention time T3 = 6 days at 5% level of significance. The removal efficiency for nitrate was determined to be 81%. Refer Appendix B10 for further detailed on the removal efficiency calculation.

The phosphorus removal efficiency was calculated and it gave a value of 67% of removal. Based on the statistical analysis conducted, there is a significant difference between wetland tank and control tank at detention time T3 = 6 days at 5% level of significance. Refer Appendix B11 for the removal efficiency calculation.

Based on statistical analysis conducted, there is no significant difference for nitrate concentration between wetland tank and control tank at detention time T3 = 6 days at 5% level of significance. The removal efficiency for nitrate was determined to be 92%. Refer Appendix B12 for further detailed on the removal efficiency calculation.

Water hyacinth has shown growth and development starting from day 6 until day 24 with growth rate 0.33 shoot/ day to 0.38 shoot/ day. Moreover, water hyacinth has shown its ability to survive in high concentration of nutrients.

For a further study, it is recommended to vary the flowrate of the influent municipal wastewater in order to determine the most effective removal efficiency. Longer sampling days up to harvesting period would be better as maximum plant uptake can be determined. Larger setting of detention time for each compartment should be conducted, so that the variation of concentration for each compartment much more desirable. Therefore, phosphorus and nitrate removal from UTP's municipal wastewater sewage treatment plant effluent using water hyacinth is highly recommended.

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APPENDICES

A – Raw data and results

B – Statistical analysis and calculations

C – Gantt chart

A1 Raw data of influent and treated effluent municipal wastewater

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
0	2/9/2008	COD (mg/L)							
		1	83	52	51	27	45	38	32
		2	74	54	50	39	46	62	46
		3	96	47	32	13	21	47	35
		AVERAGE	84	51	44	26	37	49	38
		Ammonia (mg/L NH_3-N)							
		1	12.85	2.96	2.25	1.94	9.19	9.11	9.17
		2	12.73	2.74	2.21	1.91	8.94	9.04	9.10
		3	12.46	2.45	2.14	1.93	8.52	9.01	8.81
		AVERAGE	12.68	2.72	2.20	1.93	8.88	9.05	9.03
		Phosphorus (mg/L PO_4^{3-})							
		1	5.51	3.11	2.79	2.67	3.11	3.24	3.32
		2	5.61	2.99	2.98	2.64	3.46	3.18	3.38
		3	5.45	3.76	2.91	2.8	3.43	3.23	3.39
		AVERAGE	5.52	3.29	2.89	2.70	3.33	3.22	3.36
		Nitrate (mg/L NO_3- - N)							
		1	9.40	6.30	7.30	5.80	5.00	5.10	5.70
		2	10.10	5.50	5.90	4.30	3.50	4.30	5.00
		3	8.90	6.00	6.70	4.00	6.00	4.80	6.30
		AVERAGE	9.47	5.93	6.63	4.70	4.83	4.73	5.67
DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
2	4/9/2008	COD (mg/L)							
		1	134	72	39	91	67	90	59
		2	96	61	47	75	69	68	89
		3	105	68	80	40	89	94	53
		AVERAGE	112	67	55	67	75	81	67
		Ammonia (mg/L NH_3-N)							
		1	10.60	3.09	2.09	2.59	6.73	6.54	6.24
		2	10.42	2.86	2.1	2.53	6.87	6.41	6.14
		3	10.65	2.91	2.08	2.55	6.84	6.32	6.08
		AVERAGE	10.53	2.95	2.09	2.56	6.81	6.42	6.15
		Phosphorus (mg/L PO_4^{3-})							
		1	5.35	1.71	1.26	1.64	2.34	2.16	2.05
		2	3.49	1.55	1.97	1.39	2.97	2.93	1.99
		3	4.41	1.99	2.86	1.27	2.82	2.83	2.81
		AVERAGE	4.42	1.75	2.03	1.43	2.71	2.64	2.28
		Nitrate (mg/L NO_3- - N)							
		1	10.50	2.70	2.50	3.60	3.20	3.30	4.00
		2	11.40	2.80	2.80	3.40	3.10	3.60	4.20
		3	9.80	2.80	2.70	3.40	3.40	3.20	4.10
		AVERAGE	10.57	2.77	2.67	3.47	3.23	3.37	4.10

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
4	6/9/2008	**COD** (mg/L)							
		1	20	23	32	26	38	40	43
		2	48	24	28	28	30	37	31
		3	27	37	33	36	45	52	42
		AVERAGE	**32**	**28**	**31**	**30**	**38**	**43**	**39**
		Ammonia (mg/L NH_3-N)							
		1	8.50	3.47	3.3	2.95	6.03	5.94	5.74
		2	8.74	3.37	3.32	2.93	5.97	5.92	5.45
		3	8.70	3.49	3.33	2.88	5.93	5.88	5.55
		AVERAGE	**8.65**	**3.44**	**3.32**	**2.92**	**5.98**	**5.91**	**5.58**
		Phosphorus (mg/L PO_4^{3-})							
		1	5.43	1.31	1.75	1.63	2.69	2.46	2.81
		2	4.28	1.94	2.35	1.7	2.44	2.42	2.98
		3	3.28	1.78	1.84	0.87	1.33	2.66	2.65
		AVERAGE	**4.33**	**1.68**	**1.98**	**1.34**	**2.15**	**2.51**	**2.81**
		Nitrate (mg/L NO_3- - N)							
		1	4.40	2.30	2.20	2.40	3.50	3.60	4.80
		2	2.80	2.30	2.40	2.20	3.00	3.30	4.50
		3	5.10	2.10	2.50	2.60	3.20	3.50	4.20
		AVERAGE	**4.10**	**2.23**	**2.37**	**2.40**	**3.23**	**3.47**	**4.50**
DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
6	8/9/2008	**COD** (mg/L)							
		1	49	24	41	32	30	31	26
		2	40	17	30	36	19	22	23
		3	29	38	13	3	21	27	22
		AVERAGE	**39**	**26**	**28**	**24**	**23**	**27**	**24**
		Ammonia (mg/L NH_3-N)							
		1	11.84	4.44	3.52	2.95	5.32	4.88	4.42
		2	11.18	4.31	3.53	2.88	5.20	4.97	4.35
		3	11.42	4.47	3.54	2.91	5.22	4.96	4.33
		AVERAGE	**11.48**	**4.41**	**3.53**	**2.91**	**5.25**	**4.94**	**4.37**
		Phosphorus (mg/L PO_4^{3-})							
		1	4.61	1.53	1.52	1.54	2.59	2.51	2.54
		2	4.54	1.58	1.47	1.53	2.61	2.48	2.49
		3	5.08	1.58	1.50	1.50	2.62	2.54	2.45
		AVERAGE	**4.74**	**1.56**	**1.50**	**1.52**	**2.61**	**2.51**	**2.49**
		Nitrate (mg/L NO_3- - N)							
		1	2.70	2.40	2.30	2.80	4.50	4.40	4.70
		2	2.90	2.40	2.40	2.80	3.60	3.70	4.50
		3	2.80	2.30	2.30	2.60	4.00	4.10	4.70
		AVERAGE	**2.80**	**2.37**	**2.33**	**2.73**	**4.03**	**4.07**	**4.63**

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
8	10/9/2008	**COD** (mg/L)							
		1	25	12	15	19	19	20	21
		2	35	27	22	18	18	25	24
		3	30	14	28	22	23	9	10
		AVERAGE	**30**	**18**	**22**	**20**	**20**	**18**	**18**
		Ammonia (mg/L NH_3-N)							
		1	9.13	4.01	3.57	3.04	3.59	4.11	4.12
		2	9.21	4.04	3.55	3.04	3.71	4.06	4.26
		3	9.11	4.11	3.49	3.00	3.65	4.05	4.00
		AVERAGE	**9.15**	**4.05**	**3.54**	**3.03**	**3.65**	**4.07**	**4.13**
		Phosphorus (mg/L PO_4^{3-})							
		1	2.77	1.60	1.61	1.53	2.47	2.47	2.40
		2	2.95	1.80	1.64	1.60	2.40	2.32	2.47
		3	2.81	1.77	1.70	1.51	2.39	2.44	2.33
		AVERAGE	**2.84**	**1.72**	**1.65**	**1.55**	**2.42**	**2.41**	**2.40**
		Nitrate (mg/L NO_3^- - N)							
		1	5.50	2.60	2.50	2.90	3.00	3.40	4.40
		2	5.60	2.10	2.40	2.60	3.50	3.60	4.50
		3	4.90	2.30	2.50	2.40	3.40	3.40	4.90
		AVERAGE	**5.33**	**2.33**	**2.47**	**2.63**	**3.30**	**3.47**	**4.60**
DAY	**DATE**	**Sample**	**I**	**W1**	**W2**	**W3**	**C1**	**C2**	**C3**
		TEST							
10	12/9/2008	**COD** (mg/L)							
		1	48	21	30	28	12	37	32
		2	44	19	7	8	18	18	21
		3	43	12	15	9	23	9	7
		AVERAGE	**45**	**17**	**17**	**15**	**18**	**21**	**20**
		Ammonia (mg/L NH_3-N)							
		1	10.7	3.1	2.3	2.9	3.4	3.2	2.5
		2	10.7	3.2	2.6	3.1	3.5	3.3	2.7
		3	10.6	3.1	2.2	3.1	3.3	3.1	2.4
		AVERAGE	**10.67**	**3.13**	**2.37**	**3.03**	**3.40**	**3.20**	**2.53**
		Phosphorus (mg/L PO_4^{3-})							
		1	3.84	1.56	1.49	1.28	2.27	2.31	2.23
		2	3.76	1.54	1.52	1.39	2.4	2.34	2.42
		3	3.61	1.48	1.53	1.31	2.33	2.38	2.13
		AVERAGE	**3.74**	**1.53**	**1.51**	**1.33**	**2.33**	**2.34**	**2.26**
		Nitrate (mg/L NO_3^- - N)							
		1	3.00	2.30	2.80	2.70	4.10	4.90	5.70
		2	3.40	2.10	2.50	2.90	4.30	4.40	4.80
		3	3.50	2.50	2.70	2.50	4.10	4.90	5.90
		AVERAGE	**3.30**	**2.30**	**2.67**	**2.70**	**4.17**	**4.73**	**5.47**

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
12	14/9/2008	**COD** (mg/L)							
		1	64	36.00	51	35	46	20	32
		2	79	47	33	50	64	49	45
		3	84	30	68	30	37	27	41
		AVERAGE	**76**	**38**	**51**	**38**	**49**	**32**	**39**
		Ammonia (mg/L NH_3-N)							
		1	10.4	3.4	2.7	2.4	4.3	3.6	3.8
		2	11	3.3	3	2.7	4.1	3.8	3.3
		3	10.5	3.5	2.6	2.9	4.3	3.6	3.9
		AVERAGE	**10.63**	**3.40**	**2.77**	**2.67**	**4.23**	**3.67**	**3.67**
		Phosphorus (mg/L PO_4^{3-})							
		1	2.25	1.75	1.64	1.53	2.03	2.02	2.21
		2	2.49	1.65	1.63	1.52	2.06	2.03	2.29
		3	2.3	1.77	1.69	1.5	2.1	2.04	2.27
		AVERAGE	**2.35**	**1.72**	**1.65**	**1.52**	**2.06**	**2.03**	**2.26**
		Nitrate (mg/L NO_3- - N)							
		1	7.5	4.2	4.4	5	4.4	4.3	5
		2	5.6	4.2	4.5	4.8	3.5	4.1	5.4
		3	8.1	3.90	4.3	5.4	4.9	3.8	5.1
		AVERAGE	**7.1**	**4.1**	**4.4**	**5.1**	**4.3**	**4.1**	**5.2**
DAY	**DATE**	**Sample**	**I**	**W1**	**W2**	**W3**	**C1**	**C2**	**C3**
		TEST							
14	16/9/2008	**COD** (mg/L)							
		1	33	27.00	27	32	54	38	39
		2	34	21	33	37	49	41	41
		3	45	39	26	40	54	30	37
		AVERAGE	**37**	**29**	**29**	**36**	**52**	**36**	**39**
		Ammonia (mg/L NH_3-N)							
		1	11.1	1.9	2.1	1.3	4.9	5.4	3.7
		2	11.3	2	2	1.5	4.8	5.8	4.5
		3	11.1	1.8	2.3	1.7	5.1	5.2	4.9
		AVERAGE	**11.17**	**1.90**	**2.13**	**1.50**	**4.93**	**5.47**	**4.37**
		Phosphorus (mg/L PO_4^{3-})							
		1	2.35	1.77	1.53	1.8	2.2	2.45	2.37
		2	2.48	1.67	1.58	1.6	2.21	2.47	2.32
		3	2.54	1.79	1.58	1.77	2.32	2.4	2.43
		AVERAGE	**2.46**	**1.74**	**1.56**	**1.72**	**2.24**	**2.44**	**2.37**
		Nitrate (mg/L NO_3- - N)							
		1	8.9	4.9	5.2	6.3	2.8	2.8	2.7
		2	8.1	4.5	5.1	6.1	2.5	3	2.5
		3	8.7	4.90	4.8	5.9	2.9	2.6	2.8
		AVERAGE	**8.6**	**4.8**	**5.0**	**6.1**	**2.7**	**2.8**	**2.7**

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
16	18/9/2008	**COD** (mg/L)							
		1	38	36.00	33	39	31	40	41
		2	45	21	29	30	61	36	35
		3	40	39	28	27	35	49	47
		AVERAGE	**41**	**32**	**30**	**32**	**42**	**42**	**41**
		Ammonia (mg/L NH_3-N)							
		1	11.5	2.2	1.2	0.9	4.5	4.1	4.1
		2	11.9	2.6	1.5	0.9	4.5	4.5	4.4
		3	11.8	2.3	1.3	1	4.3	4.4	4.1
		AVERAGE	**11.73**	**2.37**	**1.33**	**0.93**	**4.43**	**4.33**	**4.20**
		Phosphorus (mg/L PO_4^{3-})							
		1	3.56	1.62	1.67	1.45	2.42	2.46	2.33
		2	4.98	1.78	1.84	1.71	2.46	2.48	2.45
		3	4.86	1.46	1.54	1.62	2.66	1.97	2.37
		AVERAGE	**4.47**	**1.62**	**1.68**	**1.59**	**2.51**	**2.30**	**2.38**
		Nitrate (mg/L NO_3- - N)							
		1	8.4	5.3	5.3	5.4	2.9	2.8	3.2
		2	6.9	4.8	5.1	5.3	2.5	3.1	3.2
		3	7.3	4.60	4.9	4.4	2	2.5	3.9
		AVERAGE	**7.5**	**4.9**	**5.1**	**5.0**	**2.5**	**2.8**	**3.4**
DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
18	20/9/2008	**COD** (mg/L)							
		1	67	55.00	40	36	29	71	96
		2	59	52	56	41	39	84	47
		3	69	58	61	33	22	62	98
		AVERAGE	**65**	**55**	**52**	**37**	**30**	**72**	**80**
		Ammonia (mg/L NH_3-N)							
		1	14.3	0.6	0.2	0	4.1	3.7	3.5
		2	13.9	0.9	0.4	0.3	4.5	3.5	3.9
		3	14.1	0.8	0.1	0.1	4.4	3.8	3.5
		AVERAGE	**14.10**	**0.77**	**0.23**	**0.13**	**4.33**	**3.67**	**3.63**
		Phosphorus (mg/L PO_4^{3-})							
		1	4.81	1.07	0.92	0.93	2.89	2.53	2.6
		2	5.06	1.61	0.93	0.92	2.71	2.51	2.62
		3	4.98	1.5	1.01	0.98	2.59	2.48	2.71
		AVERAGE	**4.95**	**1.39**	**0.95**	**0.94**	**2.73**	**2.51**	**2.64**
		Nitrate (mg/L NO_3- - N)							
		1	6.9	1.4	2	1.4	1.9	2.3	2.6
		2	5.9	1.9	3.1	1.2	2.8	2.5	1.9
		3	7.4	2.40	2.8	1.7	1	2.1	3.4
		AVERAGE	**6.7**	**1.9**	**2.6**	**1.4**	**1.9**	**2.3**	**2.6**

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
20	22/9/2008	**COD** (mg/L)							
		1	61	16	18	21	36	27	37
		2	67	12	11	19	30	21	44
		3	70	20	24	22	37	29	29
		AVERAGE	**66**	**16**	**18**	**21**	**34**	**26**	**37**
		Ammonia (mg/L NH_3-N)							
		1	15.7	0.3	0.1	0.2	4.2	5.8	4.2
		2	15.8	0.3	0.3	0.4	4.8	5.9	3.9
		3	15.6	0.1	0.1	0.3	4.5	5.1	5.0
		AVERAGE	**15.70**	**0.23**	**0.17**	**0.30**	**4.50**	**5.60**	**4.37**
		Phosphorus (mg/L PO_4^{3-})							
		1	5.18	0.88	0.73	0.96	2.86	2.85	2.7
		2	6.01	0.89	0.67	0.92	2.88	2.81	2.58
		3	5.34	0.71	0.77	1.01	2.91	2.81	2.77
		AVERAGE	**5.51**	**0.83**	**0.72**	**0.96**	**2.88**	**2.82**	**2.68**
		Nitrate (mg/L NO_3^- - N)							
		1	3.1	1.3	1.3	1.2	2.8	2.5	2.8
		2	3.9	1.3	1.3	1.1	2.9	2.8	2.9
		3	3.5	1.20	1	1.1	2.6	2.1	1.4
		AVERAGE	**3.5**	**1.3**	**1.2**	**1.1**	**2.8**	**2.5**	**2.4**
DAY	**DATE**	**Sample**	**I**	**W1**	**W2**	**W3**	**C1**	**C2**	**C3**
		TEST							
22	24/9/2008	**COD** (mg/L)							
		1	30	22	18	23	36	27	37
		2	62	28	15	19	34	27	44
		3	69	20	24	24	37	29	39
		AVERAGE	**54**	**23**	**19**	**22**	**36**	**28**	**40**
		Ammonia (mg/L NH_3-N)							
		1	16.8	3.4	4.8	3.9	7.3	8.1	10.4
		2	15.6	4.5	3.7	3.7	8.6	7.9	9.4
		3	14.8	4.3	4.4	4.1	7.9	8.2	8.9
		AVERAGE	**15.73**	**4.07**	**4.30**	**3.90**	**7.93**	**8.07**	**9.57**
		Phosphorus (mg/L PO_4^{3-})							
		1	10.12	7.54	3.55	2.89	6.89	5.34	4.33
		2	9.83	8.9	4.51	2.34	6.66	4.9	3.76
		3	10.47	7.66	4.89	2.65	6.61	5.23	4.76
		AVERAGE	**10.14**	**8.03**	**4.32**	**2.63**	**6.72**	**5.16**	**4.28**
		Nitrate (mg/L NO_3^- - N)							
		1	9.7	5.9	3.9	4.7	7.3	5.5	6.8
		2	10.1	6.1	3.8	4.4	8.7	4.9	8.7
		3	9.4	5.80	3	5.6	7.5	5.3	6.1
		AVERAGE	**9.7**	**5.9**	**3.6**	**4.9**	**7.8**	**5.2**	**7.2**

DAY	DATE	Sample	I	W1	W2	W3	C1	C2	C3
		TEST							
24	26/9/2008	**COD** (mg/L)							
		1	79	34	31	12	36	39	37
		2	62	28	20	19	34	30	44
		3	69	30	24	9	37	29	39
		AVERAGE	**70**	**31**	**25**	**13**	**36**	**33**	**40**
		Ammonia (mg/L NH_3-N)							
		1	14	3.4	2.5	2	5.4	6.5	8.4
		2	15.6	4.5	3.7	2.3	5.3	7.9	9.4
		3	13.9	2.8	3.1	1.3	6.3	6.1	8.9
		AVERAGE	**14.50**	**3.57**	**3.10**	**1.87**	**5.67**	**6.83**	**8.90**
		Phosphorus (mg/L PO_4^{3-})							
		1	10.12	7.22	3.55	2.22	6.89	5.12	4.12
		2	9.83	4.41	4.51	2.34	6.23	4.9	3.76
		3	10.22	6.3	4.22	2.65	6.61	5.22	4.01
		AVERAGE	**10.06**	**5.98**	**4.09**	**2.40**	**6.58**	**5.08**	**3.96**
		Nitrate (mg/L NO_3^- - N)							
		1	8.5	5.9	3.9	4.7	8.3	4.5	5.8
		2	10.1	4.4	3.2	4.4	6.7	3.9	7.7
		3	8.5	4.30	2.9	3.6	6.5	4.3	5.1
		AVERAGE	**9.0**	**4.9**	**3.3**	**4.2**	**7.2**	**4.2**	**6.2**

A2 Influent concentration of municipal wastewater

mg/L	I			
Day	COD	NH3	P	NO3
0	84	12.68	5.52	9.5
2	112	10.53	4.42	10.57
4	32	8.65	4.33	4.1
6	39	11.48	4.74	2.8
8	30	9.15	2.84	5.33
10	45	10.67	3.74	3.3
12	76	11.3	2.35	7.07
14	37	11.17	2.46	8.57
16	41	11.73	4.47	7.53
18	65	14.1	4.95	6.73
20	66	15.7	5.51	3.5
22	54	15.73	10.14	9.73
24	70	14.5	10.06	9.03

A3 Effluent concentration of municipal wastewater in reactor tank A

mg/L	W1				W2				W3			
Day	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3
0	51	2.72	3.29	5.9	44	2.2	2.89	6.6	26	1.93	2.7	4.7
2	67	2.95	1.75	2.77	55	2.09	2.03	2.67	67	2.56	1.43	3.47
4	28	3.44	1.68	2.23	31	3.32	1.98	2.37	30	2.92	1.34	2.4
6	26	4.41	1.56	2.34	28	3.53	1.5	2.33	24	2.91	1.52	2.73
8	18	4.05	1.72	2.33	22	3.54	1.65	2.47	20	3.03	1.55	2.63
10	17	3.13	1.53	2.3	17	2.37	1.51	2.67	15	3.03	1.33	2.7
12	38	3.6	1.72	4.1	51	3.23	1.65	4.4	38	3.13	1.52	5.07
14	29	1.9	1.74	4.77	29	2.13	1.56	5.03	36	1.5	1.72	6.1
16	32	2.37	1.62	4.9	30	1.33	1.68	5.1	32	0.93	1.59	5.03
18	55	0.77	1.39	1.9	52	0.23	0.95	2.63	37	0.13	0.94	1.43
20	16	0.23	0.83	1.27	18	0.17	0.72	1.2	21	0.3	0.96	1.13
22	23	5.77	4.07	5.93	19	4.3	4.3	3.57	22	5.87	3.9	4.9
24	31	3.57	5.98	4.87	25	3.1	4.09	3.33	13	1.867	2.4	4.23

A4 Effluent concentration of municipal wastewater in reactor tank B

mg/L	C1				C2				C3			
Day	COD	NH3	P	NO3	COD	NH3	P	NO_3	COD	NH3	P	NO_3
0	37	8.88	3.33	4.8	49	9.05	3.22	4.7	38	9.03	3.36	5.7
2	75	6.81	2.71	3.23	81	6.42	2.64	3.37	67	6.15	2.28	4.1
4	38	5.98	2.15	3.23	43	5.91	2.51	3.47	39	5.58	2.81	4.5
6	23	5.25	2.61	4.03	27	4.94	2.51	4.07	24	4.37	2.49	4.63
8	20	3.65	2.42	3.3	18	4.07	2.41	3.47	18	4.13	2.4	4.6
10	18	3.4	2.32	4.17	21	3.2	2.34	4.73	20	2.53	2.26	5.47
12	49	4.2	2.06	4.27	32	4.43	2.03	4.07	39	5.27	2.26	5.17
14	52	4.93	2.24	2.73	36	5.47	2.44	2.8	39	4.37	2.37	2.67
16	42	4.43	2.51	2.47	42	4.33	2.3	2.8	41	4.2	2.38	3.43
18	30	4.33	2.73	1.9	72	3.67	2.51	2.3	80	3.63	2.64	2.63
20	34	4.5	2.88	2.77	26	5.6	2.82	2.47	37	4.37	2.68	2.37
22	36	7.93	6.72	7.83	28	8.07	5.16	5.23	40	9.57	4.28	7.2
24	36	5.67	6.58	7.17	33	6.83	5.08	4.23	40	8.9	3.96	6.2

A5 Plant uptake data for reactor tank A

mg/L	I				W1				Plant Uptake (mg/L)				Plant Uptake (mg/day/ shoot)			
Day	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3
0	84	12.68	5.52	9.5	51	2.72	3.29	5.9	0	0	0	0	0	0	0	0
2	112	10.53	4.42	10.57	67	2.95	1.75	2.77	17	9.73	3.77	6.73	0	0	0	0
4	32	8.65	4.33	4.1	28	3.44	1.68	2.23	84	7.09	2.74	8.34	0	0	0	0
6	39	11.48	4.74	2.8	26	4.41	1.56	2.34	6	4.24	2.77	1.76	72	50.88	33.24	21.12
8	30	9.15	2.84	5.33	18	4.05	1.72	2.33	21	7.43	3.02	0.47	252	89.16	36.24	5.64
10	45	10.67	3.74	3.3	17	3.13	1.53	2.3	13	6.02	1.31	3.03	156	72.24	15.72	36.36
12	76	11.3	2.35	7.07	38	3.6	1.72	4.1	7	7.07	2.02	-0.8	42	42.42	12.12	-4.8
14	37	11.17	2.46	8.57	29	1.9	1.74	4.77	47	9.4	0.61	2.3	282	56.4	3.66	13.8
16	41	11.73	4.47	7.53	32	2.37	1.62	4.9	5	8.8	0.84	3.67	30	52.8	5.04	22.02
18	65	14.1	4.95	6.73	55	0.77	1.39	1.9	-14	10.96	3.08	5.63	-56	43.84	12.32	22.52
20	66	15.7	5.51	3.5	16	0.23	0.83	1.27	49	13.87	4.12	5.46	196	55.48	16.48	21.84
22	54	15.73	10.14	9.73	23	5.77	4.07	5.93	43	9.93	1.44	-2.43	172	39.72	5.76	-9.72
24	70	14.5	10.06	9.03	31	3.57	5.98	4.87	23	12.16	4.16	4.86	92	48.64	16.64	19.44

mg/L	W1				W2				Plant Uptake (mg/L)				Plant Uptake (mg/day/shoot)			
Day	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3
0	84	12.68	5.52	9.5	44	2.2	2.89	6.6	0	0	0	0	0	0	0	0
2	112	10.53	4.42	10.57	55	2.09	2.03	2.67								
4	32	8.65	4.33	4.1	31	3.32	1.98	2.37	53	9.36	3.54	7.13	0	0	0	0
6	39	11.48	4.74	2.8	28	3.53	1.5	2.33								
8	30	9.15	2.84	5.33	22	3.54	1.65	2.47	10	5.11	2.68	1.63	120	61.32	32.16	19.56
10	45	10.67	3.74	3.3	17	2.37	1.51	2.67								
12	76	11.3	2.35	7.07	51	3.23	1.65	4.4	-21	5.92	1.19	0.93	-252	71.04	14.28	11.16
14	37	11.17	2.46	8.57	29	2.13	1.56	5.03								
16	41	11.73	4.47	7.53	30	1.33	1.68	5.1	46	9.97	0.67	1.97	276	59.82	4.02	11.82
18	65	14.1	4.95	6.73	52	0.23	0.95	2.63								
20	66	15.7	5.51	3.5	18	0.17	0.72	1.2	23	11.56	3.75	6.33	92	46.24	15	25.32
22	54	15.73	10.14	9.73	19	4.3	4.3	3.57								
24	70	14.5	10.06	9.03	25	3.1	4.09	3.33	41	12.6	1.42	0.17	164	50.4	5.68	0.68

mg/L	I				W3				Plant Uptake (mg/L)				Plant Uptake (mg/day/shoot)			
Day	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3	COD	NH3	P	NO3
0	84	12.68	5.52	9.5	26	1.93	2.7	4.7	0	0	0.00	0	0	0	0	0
2	112	10.53	4.42	10.57	67	2.56	1.43	3.47								
4	32	8.65	4.33	4.1	30	2.92	1.34	2.4								
6	39	11.48	4.74	2.8	24	2.91	1.52	2.73	60	9.77	4	6.77	720	117.24	48	81.24
8	30	9.15	2.84	5.33	20	3.03	1.55	2.63								
10	45	10.67	3.74	3.3	15	3.03	1.33	2.7								
12	76	11.3	2.35	7.07	38	3.13	1.52	5.07	1	8.35	3.22	-2.27	6	50.1	19.32	-13.62
14	37	11.17	2.46	8.57	36	1.5	1.72	6.1								
16	41	11.73	4.47	7.53	32	0.93	1.59	5.03								
18	65	14.1	4.95	6.73	37	0.13	0.94	1.43	39	11.17	1.41	5.64	156	44.68	5.64	22.56
20	66	15.7	5.51	3.5	21	0.3	0.96	1.13								
22	54	15.73	10.14	9.73	22	5.87	3.9	4.9								
24	70	14.5	10.06	9.03	13	1.867	2.4	4.23	52	12.233	2.55	2.5	208	48.932	10.2	10

A6 Growth rate data

day	new water hyacinth	new water hyacinth/day
0	0	0.00
2	0	0.00
4	0	0.00
6	2	0.33
8	2	0.25
10	2	0.20
12	3	0.25
14	4	0.29
16	5	0.31
18	5	0.28
20	7	0.35
22	7	0.32
24	9	0.38

B1 T-Test data analysis at 5% level of significance for detention time T1 = 2 days

COD A-T1	COD B-T1
51	37
67	75
28	38
26	23
18	20
17	18
38	49
29	52
32	42
55	30
16	34
23	36
31	36

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	33.15384615	37.69230769
Variance		228.2307692
Observations	13	13
Pooled Variance	237.1858974	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.751313004	
P(T<=t) one-tail	0.229884327	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.459768655	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between COD of the Reactor A and Reactor B at 5% level of significance.

NH_3 A-T1	NH_3 B-T1
2.72	8.88
2.95	6.81
3.44	5.98
4.41	5.25
4.05	3.65
3.13	3.4
3.6	4.2
1.9	4.93
2.37	4.43
0.77	4.33
0.23	4.5
5.77	7.93
3.57	5.67

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.993076923	5.381538462
Variance	2.165989744	2.712164103
Observations	13	13
Pooled Variance	2.439076923	
Hypothesized Mean Difference	0	
df	24	
t Stat	-3.899080323	
P(T<=t) one-tail	0.000339853	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.000679707	
t Critical two-tail	2.063898547	

Since t Stat < -2.0639, therefore reject Ho=0, and conclude that there is a significant difference between Ammonia of the Reactor A and Reactor B at 5% level of significance.

NO_3 A-T1	NO_3 B-T1
5.9	4.8
2.77	3.23
2.23	3.23
2.34	4.03
2.33	3.3
2.3	4.17
4.1	4.27
4.77	2.73
4.9	2.47
1.9	1.9
1.27	2.77
5.93	7.83
4.87	7.17

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.508461538	3.992307692
Variance	2.608914103	3.084352564
Observations	13	13
Pooled Variance	2.846633333	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.731136064	
P(T<=t) one-tail	0.235887299	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.471774597	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between Nitrate of the Reactor A and Reactor B at 5% level of significance.

P A-T1	P B-T1
3.29	3.33
1.75	2.71
1.68	2.15
1.56	2.61
1.72	2.42
1.53	2.32
1.72	2.06
1.74	2.24
1.62	2.51
1.39	2.73
0.83	2.88
4.07	6.72
5.98	6.58

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.221538462	3.173846154
Variance	1.986714103	2.493075641
Observations	13	13
Pooled Variance	2.239894872	
Hypothesized Mean Difference	0	
df	24	
t Stat	-1.622258853	
P(T<=t) one-tail	0.058906307	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.117812614	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus of the Reactor A and Reactor B at 5% level of significance.

B2 T-Test data analysis at 5% level of significance for detention time T2 = 4 days

COD A-T2	COD B-T2
44	49
55	81
31	43
28	27
22	18
17	21
51	32
29	36
30	42
52	72
18	26
19	28
25	33

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	32.38461538	39.07692308
Variance	183.4230769	355.9102564
Observations	13	13
Pooled Variance	269.6666667	
Hypothesized Mean Difference	0	
df	24	
t Stat	-1.039008128	
P(T<=t) one-tail	0.154577979	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.309155958	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between COD of the Reactor A and Reactor B at 5% level of significance.

NH_3 A-T2	NH_3 B-T2
2.2	9.05
2.09	6.42
3.32	5.91
3.53	4.94
3.54	4.07
2.37	3.2
3.23	4.43
2.13	5.47
1.33	4.33
0.23	3.67
0.17	5.6
4.3	8.07
3.1	6.83

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.426153846	5.537692308
Variance	1.603292308	2.957869231
Observations	13	13
Pooled Variance	2.280580769	
Hypothesized Mean Difference	0	
df	24	
t Stat	-5.253020831	
P(T<=t) one-tail	1.09634E-05	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	2.19268E-05	
t Critical two-tail	2.063898547	

Since t Stat < -2.0639, therefore reject Ho=0, and conclude that . there is a significant difference between Ammonia of the Reactor A and
Reactor B at 5% level of significance.

NO_3 A-T2	NO_3 B-T2
6.6	4.7
2.67	3.37
2.37	3.47
2.33	4.07
2.47	3.47
2.67	4.73
4.4	4.07
5.03	2.8
5.1	2.8
2.63	2.3
1.2	2.47
3.57	5.23
3.33	4.23

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.413076923	3.67
Variance	2.198989744	0.854366667
Observations	13	13
Pooled Variance	1.526678205	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.530134466	
P(T<=t) one-tail	0.300444808	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.600889617	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between Nitrate of the Reactor A and Reactor B at 5% level of significance.

P A-T2	P B-T2
2.89	3.22
2.03	2.64
1.98	2.51
1.5	2.51
1.65	2.41
1.51	2.34
1.65	2.03
1.56	2.44
1.68	2.3
0.95	2.51
0.72	2.82
4.3	5.16
4.09	5.08

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.039230769	2.920769231
Variance	1.183624359	1.030774359
Observations	13	13
Pooled Variance	1.107199359	
Hypothesized Mean Difference	0	
df	24	
t Stat	-2.135920238	
P(T<=t) one-tail	0.021545088	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.043090175	
t Critical two-tail	2.063898547	

Since t Stat < -2.0639, therefore reject Ho=0, and conclude that . there is a significant difference between Phosphorus of the Reactor A and Reactor B at 5% level of significance.

B3 T-Test data analysis at 5% level of significance for detention time T3 = 6 days

COD A-T3	COD B-T3
26	38
67	67
30	39
24	24
20	18
15	20
38	39
36	39
32	41
37	80
21	37
22	40
13	40

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	29.30769231	40.15384615
Variance	193.8974359	290.474359
Observations	13	13
Pooled Variance	242.1858974	
Hypothesized Mean Difference	0	
df	24	
t Stat	-1.77687965	
P(T<=t) one-tail	0.044133272	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.088266544	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between COD of the Reactor A and Reactor B at 5% level of significance.

NH_3 A-T3	NH_3 B-T3
1.93	9.03
2.56	6.15
2.92	5.58
2.91	4.37
3.03	4.13
3.03	2.53
3.13	5.27
1.5	4.37
0.93	4.2
0.13	3.63
0.3	4.37
5.87	9.57
1.867	8.9

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.315923077	5.546153846
Variance	2.239216077	5.062942308
Observations	13	13
Pooled Variance	3.651079192	
Hypothesized Mean Difference	0	
df	24	
t Stat	-4.310023137	
P(T<=t) one-tail	0.000120053	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.000240106	
t Critical two-tail	2.063898547	

Since t Stat < -2.0639, therefore reject Ho=0, and conclude that . there is a significant difference between Ammonia of the Reactor A and Reactor B at 5% level of significance.

NO_3^- A-T3	NO_3 B-T3
4.7	5.7
3.47	4.1
2.4	4.5
2.73	4.63
2.63	4.6
2.7	5.47
5.07	5.17
6.1	2.67
5.03	3.43
1.43	2.63
1.13	2.37
4.9	7.2
4.23	6.2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.578461538	4.513076923
Variance	2.376764103	2.14350641
Observations	13	13
Pooled Variance	2.260135256	
Hypothesized Mean Difference	0	
df	24	
t Stat	-1.5849749	
P(T<=t) one-tail	0.063030789	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.126061579	
t Critical two-tail	2.063898547	

Since -2.0639 < t Stat < 2.0639, therefore accept Ho=0, and conclude that there is NO significant difference between Nitrate of the Reactor A and Reactor B at 5% level of significance.

P A-T3	P B-T3
2.7	3.36
1.43	2.28
1.34	2.81
1.52	2.49
1.55	2.4
1.33	2.26
1.52	2.26
1.72	2.37
1.59	2.38
0.94	2.64
0.96	2.68
3.9	4.28
2.4	3.96

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	1.761538462	2.782307692
Variance	0.653764103	0.446385897
Observations	13	13
Pooled Variance	0.550075	
Hypothesized Mean Difference	0	
df	24	
t Stat	-3.508918613	
P(T<=t) one-tail	0.000901077	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.001802154	
t Critical two-tail	2.063898547	

Since t Stat < -2.0639, therefore reject Ho=0, and conclude that . there is a significant difference between Phosphorus of the Reactor A and Reactor B at 5% level of significance.

B4 T- Test data analysis at 5% level of significance for COD at T1, T2 and T3

REACTOR A

COD A-T1	COD A-T2
51	44
67	55
28	31
26	28
18	22
17	17
38	51
29	29
32	30
55	52
16	18
23	19
31	25

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	33.15384615	32.38461538
Variance	246.1410256	183.4230769
Observations	13	13
Pooled Variance	214.7820513	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.133817938	
P(T<=t) one-tail	0.447331178	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.894662355	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between COD at T1 and COD at T2 of the Reactor A at 5% level of significance.

COD A-T2	COD A-T3
44	26
55	67
31	30
28	24
22	20
17	15
51	38
29	36
30	32
52	37
18	21
19	22
25	13

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	32.38461538	29.30769231
Variance	183.4230769	193.8974359
Observations	13	13
Pooled Variance	188.6602564	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.571127546	
P(T<=t) one-tail	0.286611509	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.573223018	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between COD at T2 and COD at T3 of the Reactor A at 5% level of significance.

COD A-T1	COD A-T3
51	26
67	67
28	30
26	24
18	20
17	15
38	38
29	36
32	32
55	37
16	21
23	22
31	13

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	33.15384615	29.30769231
Variance	246.1410256	193.8974359
Observations	13	13
Pooled Variance	220.0192308	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.661078464	
P(T<=t) one-tail	0.257429299	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.514858599	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between COD at T1 and COD at T3 of the Reactor A at 5% level of significance.

REACTOR B

COD B-T1	COD B-T2
37	49
75	81
38	43
23	27
20	18
18	21
49	32
52	36
42	42
30	72
34	26
36	28
36	33

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	37.69230769	39.07692308
Variance	228.2307692	355.9102564
Observations	13	13
Pooled Variance	292.0705128	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.206557978	
P(T<=t) one-tail	0.419048723	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.838097446	
t Critical two-tail	2.063898547	

Since t Stat < -2.0739, therefore reject Ho=0, and conclude that there is a significant difference between COD at T1 and COD at T2 of the Reactor B at 5% level of significance.

COD B-T2	COD B-T3
49	38
81	67
43	39
27	24
18	18
21	20
32	39
36	39
42	41
72	80
26	37
28	40
33	40

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	39.07692308	40.15384615
Variance	355.9102564	290.474359
Observations	13	13
Pooled Variance	323.1923077	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.152725253	
P(T<=t) one-tail	0.439945851	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.879891703	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between COD at T2 and COD at T3 of the Reactor A at 5% level of significance.

COD B-T1	COD B-T3
37	38
75	67
38	39
23	24
20	18
18	20
49	39
52	39
42	41
30	80
34	37
36	40
36	40

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	37.69230769	40.15384615
Variance	228.2307692	290.474359
Observations	13	13
Pooled Variance	259.3525641	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.389688896	
P(T<=t) one-tail	0.350101647	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.700203294	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between COD at T1 and COD at T3 of the Reactor A at 5% level of significance.

B5 T- Test data analysis at 5% level of significance for ammonia at T1, T2 and T3

REACTOR A

NH_3-N A-T1	NH_3-N A-T2
2.72	2.2
2.95	2.09
3.44	3.32
4.41	3.53
4.05	3.54
3.13	2.37
3.6	3.23
1.9	2.13
2.37	1.33
0.77	0.23
0.23	0.17
5.77	4.3
3.57	3.1

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.993076923	2.426153846
Variance	2.165989744	1.603292308
Observations	13	13
Pooled Variance	1.884641026	
Hypothesized Mean Difference	0	
df	24	
t Stat	1.052849981	
P(T<=t) one-tail	0.151447533	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.302895067	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NH3 at T1 and NH3 at T2 of the Reactor A at 5% level of significance.

NH_3-N A-T2	NH_3-N A-T3
2.2	1.93
2.09	2.56
3.32	2.92
3.53	2.91
3.54	3.03
2.37	3.03
3.23	3.13
2.13	1.5
1.33	0.93
0.23	0.13
0.17	0.3
4.3	5.87
3.1	1.867

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.426153846	2.315923077
Variance	1.603292308	2.239216077
Observations	13	13
Pooled Variance	1.921254192	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.202752913	
P(T<=t) one-tail	0.420518609	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.841037219	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NH3 at T2 and NH3 at T3 of the Reactor A at 5% level of significance.

NH_3-N A-T1	NH_3-N A-T3
2.72	1.93
2.95	2.56
3.44	2.92
4.41	2.91
4.05	3.03
3.13	3.03
3.6	3.13
1.9	1.5
2.37	0.93
0.77	0.13
0.23	0.3
5.77	5.87
3.57	1.867

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.993076923	2.315923077
Variance	2.165989744	2.239216077
Observations	13	13
Pooled Variance	2.20260291	
Hypothesized Mean Difference	0	
df	24	
t Stat	1.163257667	
P(T<=t) one-tail	0.128080306	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.256160612	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NH3 at T1 and NH3 at T3 of the Reactor A at 5% level of significance.

REACTOR B

NH_3-N B-T1	NH_3-N B-T2
8.88	9.05
6.81	6.42
5.98	5.91
5.25	4.94
3.65	4.07
3.4	3.2
4.2	4.43
4.93	5.47
4.43	4.33
4.33	3.67
4.5	5.6
7.93	8.07
5.67	6.83

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	5.381538462	5.537692308
Variance	2.712164103	2.957869231
Observations	13	13
Pooled Variance	2.835016667	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.236445774	
P(T<=t) one-tail	0.407546575	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.815093149	
t Critical two-tail	2.063898547	

Since t Stat < -2.0739, therefore reject Ho=0, and conclude that there is a significant difference between NH3 at T1 and NH3 at T2 of the Reactor B at 5% level of significance.

NH_3-N B-T2	NH_3-N B-T3
9.05	9.03
6.42	6.15
5.91	5.58
4.94	4.37
4.07	4.13
3.2	2.53
4.43	5.27
5.47	4.37
4.33	4.2
3.67	3.63
5.6	4.37
8.07	9.57
6.83	8.9

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	5.537692308	5.546153846
Variance	2.957869231	5.062942308
Observations	13	13
Pooled Variance	4.010405769	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.010772385	
P(T<=t) one-tail	0.495747047	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.991494094	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NH3 at T2 and NH3 at T3 of the Reactor A at 5% level of significance.

NH_3-N B-T1	NH_3-N B-T3
8.88	9.03
6.81	6.15
5.98	5.58
5.25	4.37
3.65	4.13
3.4	2.53
4.2	5.27
4.93	4.37
4.43	4.2
4.33	3.63
4.5	4.37
7.93	9.57
5.67	8.9

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	5.381538462	5.546153846
Variance	2.712164103	5.062942308
Observations	13	13
Pooled Variance	3.887553205	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.212857485	
P(T<=t) one-tail	0.416617891	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.833235783	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NH3 at T1 and NH3 at T3 of the Reactor A at 5% level of significance.

B6 T-Test data analysis at 5% level of significance for phosphorus at T1, T2 & T3

REACTOR A

P A-T1	P A-T2
3.29	2.89
1.75	2.03
1.68	1.98
1.56	1.5
1.72	1.65
1.53	1.51
1.72	1.65
1.74	1.56
1.62	1.68
1.39	0.95
0.83	0.72
4.07	4.3
5.98	4.09

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.221538462	2.039230769
Variance	1.986714103	1.183624359
Observations	13	13
Pooled Variance	1.585169231	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.369167835	
P(T<=t) one-tail	0.357619842	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.715239683	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus at T1 and Phosphorus at T2 of the Reactor A at 5% level of significance.

P A-T2	P A-T3
2.89	2.7
2.03	1.43
1.98	1.34
1.5	1.52
1.65	1.55
1.51	1.33
1.65	1.52
1.56	1.72
1.68	1.59
0.95	0.94
0.72	0.96
4.3	3.9
4.09	2.4

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.039230769	1.761538462
Variance	1.183624359	0.653764103
Observations	13	13
Pooled Variance	0.918694231	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.73864376	
P(T<=t) one-tail	0.23364296	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.467285921	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus at T2 and Phosphorus at T3 of the Reactor A at 5% level of significance.

P A-T1	P A-T3
3.29	2.7
1.75	1.43
1.68	1.34
1.56	1.52
1.72	1.55
1.53	1.33
1.72	1.52
1.74	1.72
1.62	1.59
1.39	0.94
0.83	0.96
4.07	3.9
5.98	2.4

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.221538462	1.761538462
Variance	1.986714103	0.653764103
Observations	13	13
Pooled Variance	1.320239103	
Hypothesized Mean Difference	0	
df	24	
t Stat	1.020676732	
P(T<=t) one-tail	0.158793356	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.317586712	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus at T1 and Phosphorus at T3 of the Reactor A at 5% level of significance.

REACTOR B

P B-T1	P B-T2
3.33	3.22
2.71	2.64
2.15	2.51
2.61	2.51
2.42	2.41
2.32	2.34
2.06	2.03
2.24	2.44
2.51	2.3
2.73	2.51
2.88	2.82
6.72	5.16
6.58	5.08

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.173846154	2.920769231
Variance	2.493075641	1.030774359
Observations	13	13
Pooled Variance	1.761925	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.486088689	
P(T<=t) one-tail	0.315656566	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.631313132	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus at T1 and Phosphorus at T2 of the Reactor A at 5% level of significance.

P B-T2	P B-T3
3.22	3.36
2.64	2.28
2.51	2.81
2.51	2.49
2.41	2.4
2.34	2.26
2.03	2.26
2.44	2.37
2.3	2.38
2.51	2.64
2.82	2.68
5.16	4.28
5.08	3.96

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.920769231	2.782307692
Variance	1.030774359	0.446385897
Observations	13	13
Pooled Variance	0.738580128	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.410758938	
P(T<=t) one-tail	0.342446832	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.684893665	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus at T2 and Phosphorus at T3 of the Reactor A at 5% level of significance.

P B-T1	P B-T3
3.33	3.36
2.71	2.28
2.15	2.81
2.61	2.49
2.42	2.4
2.32	2.26
2.06	2.26
2.24	2.37
2.51	2.38
2.73	2.64
2.88	2.68
6.72	4.28
6.58	3.96

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.173846154	2.782307692
Variance	2.493075641	0.446385897
Observations	13	13
Pooled Variance	1.469730769	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.823402564	
P(T<=t) one-tail	0.209193202	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.418386404	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between Phosphorus at T1 and Phosphorus at T3 of the Reactor A at 5% level of significance.

B7 T-Test data analysis at 5% level of significance for nitrate at T1, T2 and T3

REACTOR A

NO_3 A-T1	NO_3 A-T2
5.9	6.6
2.77	2.67
2.23	2.37
2.34	2.33
2.33	2.47
2.3	2.67
4.1	4.4
4.77	5.03
4.9	5.1
1.9	2.63
1.27	1.2
5.93	3.57
4.87	3.33

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.508461538	3.413076923
Variance	2.608914103	2.198989744
Observations	13	13
Pooled Variance	2.403951923	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.156845521	
P(T<=t) one-tail	0.438339295	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.876678589	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NO3 at T1 and NO3 at T2 of the Reactor A at 5% level of significance.

NO_3 A-T2	NO_3 A-T3
6.6	4.7
2.67	3.47
2.37	2.4
2.33	2.73
2.47	2.63
2.67	2.7
4.4	5.07
5.03	6.1
5.1	5.03
2.63	1.43
1.2	1.13
3.57	4.9
3.33	4.23

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.413076923	3.578461538
Variance	2.198989744	2.376764103
Observations	13	13
Pooled Variance	2.287876923	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.27876321	
P(T<=t) one-tail	0.391407224	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.782814448	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NO3 at T2 and NO3 at T2 of the Reactor A at 5% level of significance.

NO_3 A-T1	NO_3 A-T3
5.9	4.7
2.77	3.47
2.23	2.4
2.34	2.73
2.33	2.63
2.3	2.7
4.1	5.07
4.77	6.1
4.9	5.03
1.9	1.43
1.27	1.13
5.93	4.9
4.87	4.23

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.508461538	3.578461538
Variance	2.608914103	2.376764103
Observations	13	13
Pooled Variance	2.492839103	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.113033609	
P(T<=t) one-tail	0.455472046	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.910944092	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NO3 at T1 and NO3 at T3 of the Reactor A at 5% level of significance.

REACTOR B

NO_3 B-T1	NO_3 B-T2
4.8	4.7
3.23	3.37
3.23	3.47
4.03	4.07
3.3	3.47
4.17	4.73
4.27	4.07
2.73	2.8
2.47	2.8
1.9	2.3
2.77	2.47
7.83	5.23
7.17	4.23

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.992307692	3.67
Variance	3.084352564	0.854366667
Observations	13	13
Pooled Variance	1.969359615	
Hypothesized Mean Difference	0	
df	24	
t Stat	0.585551146	
P(T<=t) one-tail	0.281821635	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.563643269	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NO3 at T1 and NO3 at T2 of the Reactor A at 5% level of significance.

NO_3 B-T2	NO_3 B-T3
4.7	5.7
3.37	4.1
3.47	4.5
4.07	4.63
3.47	4.6
4.73	5.47
4.07	5.17
2.8	2.67
2.8	3.43
2.3	2.63
2.47	2.37
5.23	7.2
4.23	6.2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.67	4.513076923
Variance	0.854366667	2.14350641
Observations	13	13
Pooled Variance	1.498936538	
Hypothesized Mean Difference	0	
df	24	
t Stat	-1.755627023	
P(T<=t) one-tail	0.045954671	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.091909343	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NO3 at T2 and NO3 at T3 of the Reactor A at 5% level of significance.

NO_3 B-T1	NO_3 B-T3
4.8	5.7
3.23	4.1
3.23	4.5
4.03	4.63
3.3	4.6
4.17	5.47
4.27	5.17
2.73	2.67
2.47	3.43
1.9	2.63
2.77	2.37
7.83	7.2
7.17	6.2

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.992307692	4.513076923
Variance	3.084352564	2.14350641
Observations	13	13
Pooled Variance	2.613929487	
Hypothesized Mean Difference	0	
df	24	
t Stat	-0.821211572	
P(T<=t) one-tail	0.209804415	
t Critical one-tail	1.710882067	
P(T<=t) two-tail	0.41960883	
t Critical two-tail	2.063898547	

Since -2.0739 < t Stat < 2.0739, therefore accept Ho=0, and conclude that there is NO significant difference between NO3 at T1 and NO3 at T3 of the Reactor A at 5% level of significance.

B8 Influent flowrate calculation

The volume of reed bed is given by:

Length (L) = 90 cm

Width (W) = 40 cm

Depth (D) = 20 cm

$$\text{Volume } (m^3) = L \times W \times D$$

$$= (90 \text{ cm}) \times (40\text{m}) \times (20\text{m})$$

$$= 72\,000 \text{ cm}^3$$

The detention time found from journal is 6 days. Therefore, the flowrate is:

$$\text{Flowrate } (m^3/\text{day}) = (\text{Volume of reactor tank}) / (\text{Detention time})$$

$$= (90\,000 \text{ cm}^3) / (6 \text{ days})$$

$$= 12\,000 \text{ cm}^3/\text{day}$$

$$= \underline{12 \text{ L/day}}$$

B9 Average percentage removal of COD calculation

The average concentration for COD influent is:

(84 + 112 + 32 + 39 + 30 + 45 + 76 + 37 + 41 + 65 + 66 + 54 + 70)/ 13 = 57.77 mg/L

The average concentration for COD effluent is:

(67 + 30 + 24 + 20 + 15 + 38 + 36 + 32 + 37 + 21 + 22 + 13)/ 12 = 29.58 mg/L

Therefore, the average percentage removal of COD for Reactor A at Q = 12L/day with T = 6 days is:

$$= \frac{\text{(Influent concentration – effluent concentration)}}{\text{Influent concentration}} \times 100\%$$

$$= \frac{(57.77\ \text{mg/L} - 29.58\ \text{mg/L})}{57.77\ \text{mg/L}} \times 100\%$$

$$= 48.8\ \%$$

B10 Average percentage removal of Ammonia calculation

The average concentration for Ammonia influent is:

(12.68 + 10.53 + 8.65 + 11.48 + 9.15 + 10.67 + 11.3 + 11.17 + 11.73 + 14.1 + 15.7 + 15.73 + 14.5)/ 13 = 12.11 mg/L

The average concentration for Ammonia effluent is:

(2.56 + 2.92 + 2.91 + 3.03 + 3.03 + 3.13 + 1.50 + 0.93 + 0.13 + 0.30 + 5.87 + 1.87)/ 12 = 2.35 mg/L

Therefore, the average percentage removal of Ammonia for Reactor A at Q = 12L/day with T = 6 days is:

$$= \frac{\text{(Influent concentration – effluent concentration)}}{\text{Influent concentration}} \times 100\%$$

$$= \frac{\text{(12.11 mg/L – 2.35 mg/L)}}{\text{12.11 mg/L}} \times 100\%$$

= 80.6 %

B11 Average percentage removal of Phosphorus calculation

The average concentration for Phosphorus influent is:

(5.52 + 4.42 + 4.33 + 4.74 + 2.84 + 3.74 + 2.35 + 2.46 + 4.47 + 4.95 + 5.51 + 10.14 + 10.06)/ 13 = 5.04 mg/L

The average concentration for COD effluent is:

(1.43 + 1.34 + 152 + 1.55 + 1.33 + 1.52 + 1.72 + 1.59 + 0.94 + 0.96 + 3.9 + 2.4)/ 12 = 1.68 mg/L

Therefore, the average percentage removal of COD for Reactor A at Q = 12L/day with T = 6 days is:

$$= \frac{\text{(Influent concentration – effluent concentration)}}{\text{Influent concentration}} \times 100\%$$

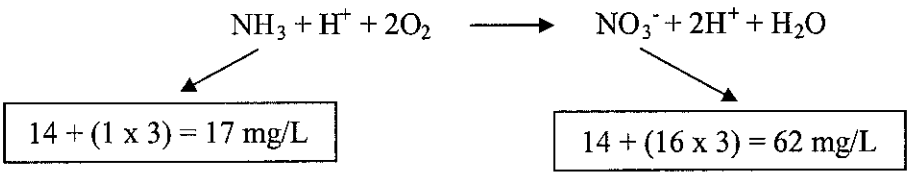
$$= \frac{\text{(5.04 mg/L – 1.68 mg/L)}}{\text{5.04 mg/L}} \times 100\%$$

= 66.7 %

B12 Average percentage removal of Nitrate calculation

The average influent concentration for Nitrate = The average influent concentration for Total Nitrate.

Total Nitrate for influent = Nitrate of influent sample + Nitrate from nitrification process.



From the above equation, 17 mg/L of Ammonia will produce 62 mg/L of Nitrate.

The average concentration of Nitrate from nitrification process:

= (average NH_3 of influent – average NH_3 of effluent) x (62/17)

= (12.11 – 2.35) x (62/17) = 35.59 mg/L

The average influent concentration of Nitrate:

(9.5 + 10.57 + 4.1 + 2.8 + 5.33 + 3.3 + 7.07 + 8.57 + 7.53 + 6.73 + 3.5 + 9.73 + 9.03)/ 13 = 6.75 mg/L

The average effluent concentration of Nitrate:

(3.47 + 2.4 + 2.73 + 2.63 + 2.7 + 5.07 + 6.1 + 5.03 + 1.43 + 1.13 + 4.9 + 4.23)/12 = 3.49 mg/L

Total Nitrate for Influent = 35.59 + 6.75 = 42.34 mg/L

Therefore, the average percentage removal of Nitrate for Reactor A at Q = 12L/day with T = 6 days is:

$$= \frac{\text{(Influent concentration – effluent concentration)}}{\text{Influent concentration}} \times 100\%$$

$$= \frac{(42.34\ \text{mg/L} - 3.49\ \text{mg/L})}{42.34\ \text{mg/L}} \times 100\%$$

$$= 91.8\ \%$$

C1 Project Gantt chart

Table 6: Project Gantt chart

PHASE	MONTH											
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dis
Research and Background Studies	■	■	■									
Visit to Putrajaya wetland				■								
Water Hyacinth habitat searching				■								
Samples (Water Hyacinth) collection					■							
Reactor tank construction						■						
Acclimatization of Water Hyacinth							■					
wastewater treatment process								■	■	■		
removal efficiency measurements											■	■